THE EARTH

AND ITS RHYTHMS

SCHUCHERT AND LeVENE

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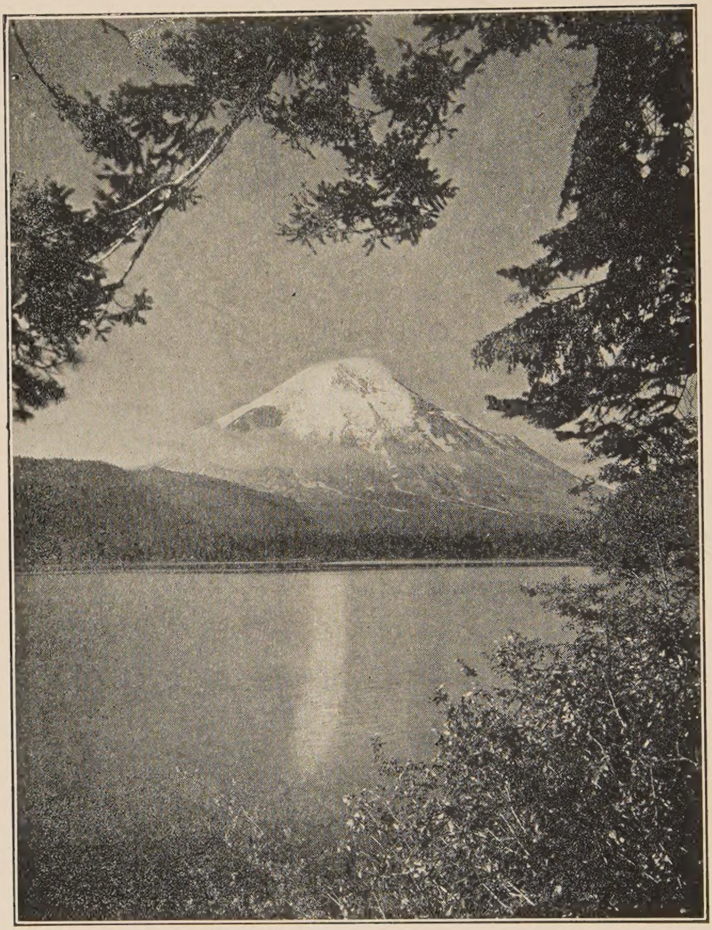

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MT. ST. HELENS FROM SPIRIT LAKE, WASHINGTON

THE EARTH
AND ITS RHYTHMS

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PREFACE

In the present age, when scientific knowledge is no longer the privilege of the few but spreading in ever widening circles into the ken of the man in the street, geology, the one science that weaves all the others together into a comprehensive whole, seems not to have received the attention it abundantly deserves. Nevertheless, it is rich in human contacts, with its practical appeal to the man whose concern is for the natural resources upon which our national prosperity rests, with its revelation to the artist of the cyclic forces that shape the landscape into lines of beauty, and, above all, with its lessons for the philosopher who is learning to view human behavior as a complex of inhibitions and impulses garnered during the long upward struggle of the race.

This very complexity, however, makes geology difficult of interpretation, and it is with full awareness of the magnitude of the task that the present authors have attempted it, remembering the naïve confession of the late Sir Archibald Geikie, long dean of British geologists, concerning his two little primers: "The composition of those two little books was one of the most difficult tasks I ever undertook. How often the manuscript of the first of them was torn up and thrown into the fire or the waste basket can not now be recalled." But fortified by the belief that the story of the rocks and the life record within them should be a part of our common intellectual heritage, we hope, by the process of filtering a great mass of geologic detail through a non-scientific mind, to have obtained a residue that will be sufficiently free of technicalities to be comprehensible to the layman.

Knowing full well that this method inevitably results at times in generalities that will horrify the geologic purist, we can only reply that the book was not intended for his perusal, and that the most we can hope for from him is that he will recommend it to his family and friends, and then spend some of his own time explaining the exceptions that are bound to outcrop in any such field of broad generalizations. If to the general reader, on the other hand, it brings some sense of the marvels that lie hidden in the rocky framework of this earth of ours, some vision of the "procession of geographies" that have preceded its present familiar contours, or some clue to the age-old puzzle of the whence and whither of man, its purpose will have been fulfilled.

For criticism of the first part of the manuscript, we are indebted to Professor Chester R. Longwell, and for many helpful suggestions and for constant encouragement, to Professor Carl O. Dunbar, both of whom, in their teaching of undergraduate geology at Yale University, have had to meet certain of the same difficulties that beset us and have generously given us the benefit of their experience in solving them. For advice regarding certain of the illustrations, our thanks are also due to Doctor Malcolm R. Thorpe of the Peabody Museum and to Doctor G. R. Wieland of the Department of Botany.

In the matter of photographs, the United States Geological Survey and other government bureaus have aided us greatly, and to them, as well as to many others who have helped us in this regard, our thanks are hereby rendered. For the illustrations showing groups of extinct vertebrates, we have made free use of the well-known restorations by such authorities as Osborn and Knight, Scott and Horsfall, Lull, Williston, and Lucas, to whom all historians of geologic time owe a considerable debt. The drawings of geologic features and of

ancient forms of life are the work of Miss M. Alice Hubbard, Mrs. Louise Nash, and Miss Lisbeth B. Krause, and the diagrams have been made by Mr. Joseph Andrews; without the sympathetic coöperation of these four, the task of illustrating the book would have been much more arduous.

C. S.
C. M. L.

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Nature is full of change. The bud we saw yesterday is a flower today; the leaf that was broad and green in summer, in autumn is shriveled and brown; the bush we knew in childhood is now a broad, spreading tree. Such changes are easily seen, because they fall within the span of a man's life, and so the principle of perpetual progress in the organic world is familiar to all. Progress in the inorganic world is so slow that it is less easily seen, and there is a widespread impression that the hills are everlasting and unchanging. This impression is false. Not only hills, but mountains, plains, and valleys, are perpetually acted on by heat and cold, sunshine and rain, wind and stream, and are gradually changed. Not only do they now undergo change, but by such agents each feature was originally formed, and by such agents it will eventually be transformed into a feature of different type. Thus every element of the landscape has an origin and a history.

GROVE KARL GILBERT

Nature vibrates with rhythms.

JOSEPH BARRELL

THE EARTH AND ITS RHYTHMS

CHAPTER I

AIR, WATER, AND SUNSHINE

CUMULUS CLOUDS

THAT we are all children of Mother Earth, dependent upon her for the very food we eat, is a self-evident fact needing no comment, but that two of the other commodities without which we cannot live—air and water—are also the gift of the earth is not so well known. These two things are ours as a rule in such abundance that we seldom consider their source, and a search for it takes us far back into the prehistory of the earth itself, before it had its present size or composition. Here we are necessarily in the realm of speculation, but

it nevertheless seems very probable that the gases which make up our air or atmosphere were exhaled from the earth as its rocks solidified, and that a part of the water with which we are so bountifully supplied has been precipitated out of this atmosphere as rain, the remainder coming from volcanoes as water-vapor (steam) or from springs in the form of hot water.

The third factor necessary to our existence, without which the other two would avail us nothing, namely, sunshine, alone comes to us from an outside source, the center of the great solar system of which the earth is so infinitesimal a part. That the earth is to-day a fit home for man is due to the interaction of these three—air, water, and sunshine—which thus form the most far-reaching example of the wonderful interdependence of the parts of Nature, or, as it is often phrased, the "web of Nature."

The air is everywhere above us and when we descend into caves or deep mines it is there also, forcing itself into all the cracks and cavities in the outermost parts of the earth, however small they may be. This is because the mantle of air which lies upon the earth, the atmosphere, has a depth of at least 100 miles and at sea-level exerts a pressure of 15 pounds to the square inch. We move about unconscious of this weight upon us, but we constantly have to overcome it in all of our motions, and in this way use up an appreciable amount of the energy supplied to the human machine by food and drink.

The atmosphere about us (the Greek word means vapor) is composed of gases, and as all gases are compressible, our air is densest at sea-level where its depth,

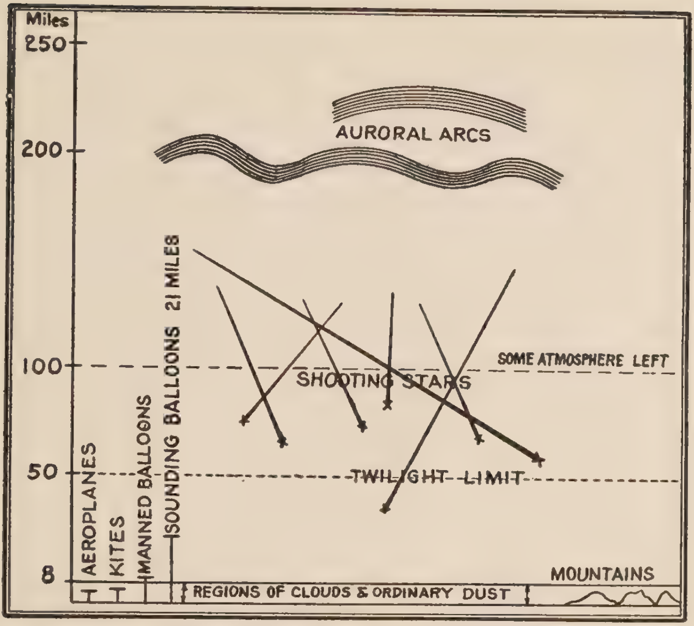


DIAGRAM TO SHOW THE MEANS OF OBTAINING INFORMATION ABOUT THE HIGHER ATMOSPHERE

Beyond the height reached by sounding balloons, all our knowledge of the earth's gaseous envelope has come from observing the height of twilight sky illumination, the paths of shooting stars, and the behavior of the auroras. After Humphreys.

and therefore the weight above, is greatest. It becomes less dense the higher we ascend, and at 19,000 feet has thinned to one-half its weight at sea-level. This means that one-half the mass of the air lies below that altitude. That the atmosphere extends far above the earth's surface, however, is indicated by the brilliant meteors, which become fiery and sparkling because of the friction they encounter as they fly through the air.

The gases of which the air is composed are not combined but simply mixed or stirred together; by using enormous pressures, the chemists can freeze this mixture into a visible solid. The air proper consists chiefly of the gaseous elements nitrogen and oxygen, about four parts of the former (78%) to one of the latter (21%), but in addition to these, argon and other elements are present in small amounts as well as various impurities that are of great value to all living things.

One of the most constant and most important of these accessory constituents of air is carbon dioxide (CO_2). This is normally present only to the extent of about three volumes in ten thousand of air, and yet, astonishing as it may appear, all plant life is basically dependent upon it for carbon. Without carbon dioxide, in fact, there could be no plants, and without plants as food there could be no animals. Much of the carbon thus taken from the air by the plants is locked up, as they decay, in the accumulating stratified rocks, while most of the oxygen is returned to the atmosphere. It is this carbon that gives most rocks their dark color, and they are said to have thirty thousand times as much of it as there is in the atmosphere. The air is thus constantly being depleted of its carbon dioxide, but, fortunately for all life, the supply is replenished by each volcanic eruption, by hot springs, by the decay of plants, etc.

A second minor constituent of the atmosphere is water-vapor, the amount of which varies according to temperature, locality, and season. Under ordinary conditions in our living rooms a cubic yard of air carries from one-fifth to two-fifths of an ounce of water, or from about one to two tablespoonfuls. This variability of

moisture in the air has much to do with climate, not only causing humid or dry ones, but bringing about some of the daily changes of temperature as well.

Still another substance present in the atmosphere is dust, thousands of particles of it being contained in every cubic inch at almost all times and within two miles of the earth's surface. This dust comes from volcanoes, from plants, from fires, and similar sources, and much of it settles very slowly. It is of importance in respect to rainfall, for rain will not ordinarily form in an atmosphere that is free of dust, but will form in a sufficiently damp atmosphere if there are dust particles present. Hence the essentials for rain are water-vapor and dust, with certain conditions of pressure and temperature present in the atmosphere.

The air is constantly in motion because the sun heats it and the surface of the earth as well, most strongly in the tropics and less in the polar regions. It is said that about one-half of the energy generated by the sunshine falling upon the equatorial belt is converted into heat and absorbed. The air can lose this heat only through slow radiation, and this process is retarded mainly by water-vapor and carbon dioxide, which therefore act as moderators of the extremes of temperature, both by day and by night and in summer and in winter. Without the atmosphere, and especially without its moisture and its carbonic acid gas, we should be subject to much greater vicissitudes of cold and heat than we are. Even so, the difference between the heat of day and the cold of night may be 50 degrees, or even as much as 75 degrees; the annual range, between the cold of winter and the heat of summer, may be 100 degrees or even as much as 150

degrees. Robert T. Hill, running the canyons of the Rio Grande in summer time, says: "One is roasted unmercifully by day by 130 degrees of sunshine, and cooled almost to the freezing point by night." These great extremes of temperature will eventually shatter even the very rocks into fragments.

Since the sun heats the atmosphere most in the tropics, the greater temperature causes the air here to expand, and, rising to higher levels, to flow toward the poles; on cooling, the air becomes denser and accordingly sinks to lower levels and moves toward the tropics. However, as the earth revolves rapidly on its axis, this north-south streaming of the air is deflected eastward and westward, bringing about the well-known trade winds and westerlies. To the north of the equator the trades, when not disturbed by storms, blow from the northeast, while to the south of it they blow in general from the southeast. On either side of the tropical trade winds are the prevailing westerlies of the temperate regions. The winds set in motion by the solar heat therefore constitute a great hot-air engine, which makes the windmills turn and the ships sail the seas, and brings the water-vapor from the oceans over the lands. Hence it is in the last analysis the sunshine that brings us the rain without which our lands would be lifeless. Moreover, sunshine, penetrating into the surficial waters of the ocean, gives rise there to the plants upon which all marine animals are dependent for food, as well as making it possible for plants to spread over the lands.

Water is a chemical compound of hydrogen and oxygen, formed by the union of two volumes of the former with one of the latter (H_2O). It occurs in three states,

namely, liquid, solid, and gaseous. At sea-level it freezes at 32 degrees Fahrenheit, and in so doing expands about one-eleventh its former volume, a property which, as we shall see later, is a factor in the breaking up of the rocks. Rain, the condensed water-vapor of the atmosphere, is the purest of natural waters, but in its fall through the air it takes up impurities, and out of the ground it dissolves certain salts and traces of organic matter. Therefore surface and underground waters are always impure, having in solution different kinds of salts, varying according to the climate and the rocks which are penetrated. As a carrier of ammonia, nitric acid, sulphuric acid, and chlorine—substances that it takes out of the air and the ground—water performs a function of the highest significance to agriculture, and to geology as well, as we shall see in subsequent chapters.

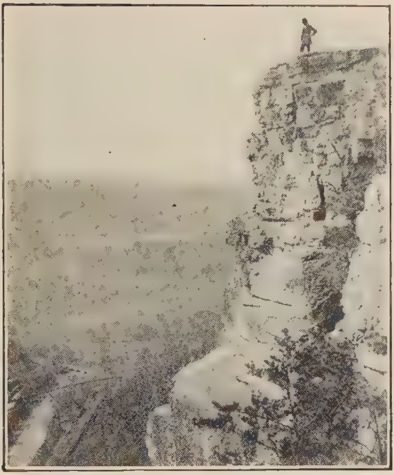
Where rainfall is abundant and the soil is naturally fertile, carbonate waters are the rule; in arid regions, sulphates and chlorides prevail. In a humid climate, plants are abundant and great quantities of carbonic acid are generated by their decay. This carbonic acid, absorbed by the ground-water of the soil, acts as a solvent of mineral matter, and carbonates are carried into the streams more abundantly than other salts. In arid regions there is less organic decomposition and less carbonic acid, and hence a smaller proportion of carbonates.

The water of the oceans, since it has received throughout the geologic ages the impurities of all the rivers, and loses very little of these on evaporation, has become highly saline. In fact, sea-water has traces of nearly all the known elements, and it is these combined that give it the well-known salty taste.

The amount of rain falling annually on all the lands is computed by Sir John Murray to be equivalent to about 29,350 cubic miles, and of this quantity less than one-fourth drains off at once through rivers to the ocean; the remainder either soaks into the ground and reappears as springs, or evaporates away. The water returning to the oceans carries with it solution material amounting annually to about 2,735,000,000 tons. "The moment that water leaves the atmosphere and enters the porous earth," says F. W. Clarke, our foremost geochemist, "its chemical and solvent activities begin, and continue, probably without interruption, until it reaches the sea."

CHAPTER II

THE EARTH'S ROCKY CRUST



SANDSTONE CLIFF, WILLS MT., MARYLAND

OUR direct knowledge of terrestrial matter is restricted to air, water, and the outermost rocks of the earth. In the previous chapter we have learned something of the first two; now we come to the discussion of the materials with which geology is most concerned, the rocks, meaning by this term only the outer shell of the earth, since its vast core or nucleus is made up essentially of metals.

Rocks are combinations of minerals, and these in turn result from chemical combinations of the various elements that make up all matter. There are about ninety of these elements, but eight of them compose nearly 98 per cent of our rocks. These are oxygen (47.33%), silicon (27.74%), aluminum (7.85%), iron (4.50%), calcium (3.47%), sodium (2.46%), potassium (2.46%), and magnesium (2.24%). Most of the other elements are therefore present only in minute quantities, but, as is

A MILE OF ROCK BELOW THE EARTH'S SURFACE

Grand Canyon, from Grand View. Photograph from Fred Harvey.

often the case with rare things, certain of these scarce elements, for instance gold and platinum, are prized far more highly than such common ones as iron and aluminum.

As a rule it takes two or more elements in combination

TWO MILES OF ROCK ABOVE SEA-LEVEL

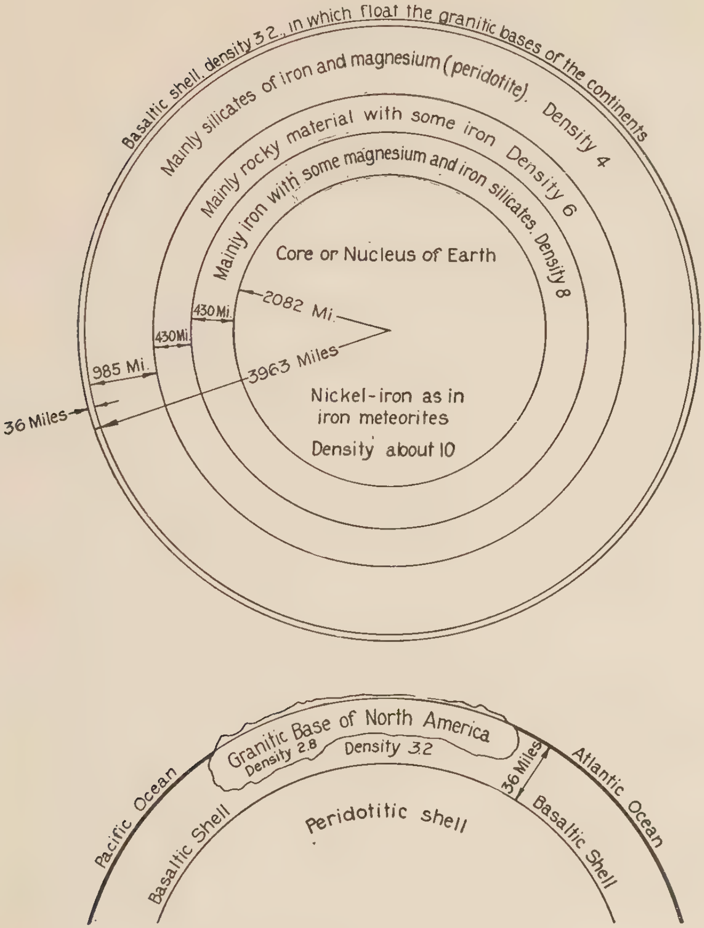
Mt. Temple, in the Canadian Rockies. Photograph by Notman.

to make a mineral, but the possible combinations of elements have resulted in over a thousand distinct kinds of natural minerals. Some minerals have also been made synthetically in the laboratory. Each mineral has a definite chemical combination and a characteristic crys-

tal form, and all are solids excepting mercury and water, for, strange as it may seem, water is classed among the minerals. Most of the kinds of minerals, like the native elements, are rare, and only about fifty of them are of common geological occurrence, while fewer than ten make up more than 90 per cent of the rocks (feldspars, quartz, hornblende, micas, calcite, kaolin, chlorite, etc.).

It is out of minerals that practically all of the earth's rocks are made, since only a few kinds originate from living matter (coal, peat, petroleum). Some, like sandstone and limestone, are composed essentially of but a single mineral, but most of the rocks are mixtures of from two to ten kinds, and some are even more complex. Rocks are usually consolidated and hard, but certain of them, like sand and clay, are incoherent and soft.

Man in his mining operations has penetrated vertically into the earth about one and a half miles, but he has tunneled many miles in a stretch through the mountains and in these regions he can see the rocks piled up 6 miles above the level of the sea. Our knowledge of the deeper lying rocks, however, down to a depth of something like 20 to 40 miles, is necessarily far less direct, but we get a fair idea of their nature from the molten or igneous rocks (magmas) that rise from these depths and intrude themselves into the higher strata or actually flow out as lava on the surface. Again, the earthquake tremors passing through and around the earth and recording themselves in the seismograph machines tell us something of the varying character of the rocks through which they pass. From these and other lines of evidence, Professor Joly of Dublin deduces that the continents, composed in the main of granites and similar rocks, which are com-



SECTION THROUGH THE EARTH

Above, the various shells of which the earth is composed. Below, portion of the outermost shell, to show how the isolated, lighter continents "float," iceberg-fashion, in the heavier basaltic rock.

paratively light, "float" upon a universal substratum of heavier and darker colored basaltic rocks. This great reservoir of basalt, he believes, covers the whole earth with a thickness estimated at from 70 to at most 200 or 300 miles, and from it at times have welled up great floods of basaltic lava. This substratum comes nearest the surface beneath the oceanic bottoms, where it is concealed only by the deep-sea deposits, which Joly thinks may have an average depth of less than 1000 feet.

The rocks making up the continents which rest upon this substratum are of three categories. Those which in general lie deepest are the igneous rocks—the "fire rocks"—so called because they once were molten and have since cooled into their present solid condition. Granite is a common example of these, porphyry another, basalt a third. We know these igneous rocks in their original solid state only where the oldest portions of the crust are exposed to view. Many times, however, when the rocks above them have been disturbed by crustal unrest, the igneous materials have welled up in a molten condition into the openings thus created, and, there resolidifying, have been subsequently brought to light by the wearing away of the surrounding rocks into which they have intruded themselves. When the molten rock or magma reaches the surface, either by being thrown out in volcanic eruptions or by flowing out quietly through great fissures as surface sheets, we know it as ash and lava.

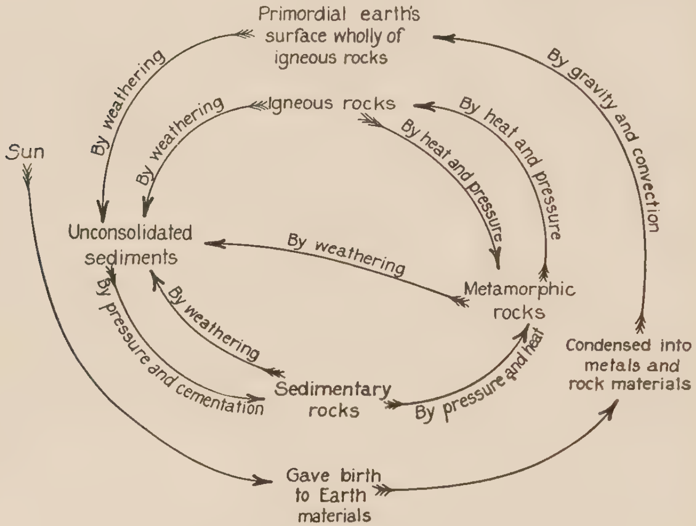
The second group of rocks, the sedimentary or stratified ones, are derived from other rocks when they break up under the influence of various agencies such as wind, water, and ice. The countless granular fragments which

result from this rock disintegration, when carried away by wind and water, assorted according to size, deposited in layers or beds, and consolidated by pressure, become the sedimentary rocks as we see them to-day. Chief among them are the conglomerates, mixtures of boulders, pebbles, or fragments held together by some kind of cement; the sandstones, composed of grains of quartz; and the mudstones, including such fine-grained rocks as clays and shales. The conglomerates and sandstones together make up about 15 per cent of the total, while the mudstones, with 80 per cent, are by far the most common. The additional 5 per cent is taken up by the limestones and calcareous or limy mudstones, which are the solution materials dissolved by water out of other rocks and precipitated mainly through organic agencies.

The great bulk of the sedimentary rocks were laid down in water, and chiefly in marine water, but some were blown together by the wind, and others were deposited by glaciers. Over the greater parts of the continents they have thicknesses varying between a few hundred feet and two miles, while in certain definite areas (the geosynclines) these accumulations of the ages range between four and thirteen miles in depth. Compared with the rest of the crust, their quantity is small, but in them lies most of the readable history of the earth, for it is in these sedimentaries that we find the fossils, remains of once living plants and animals, with their wonderful story of the evolution of life.

Still a third kind of rocks is produced when either the igneous rocks or the sedimentary ones undergo alteration due to heat and pressure. This may take place in several ways. The deep-lying igneous rocks, as we have seen,

frequently are reheated to the melting point, and in this molten condition may force their way upward into the rocks above them. The rocks thus cut through or intruded by the magmas undergo, because of the resulting heat and pressure, a more or less complete mineral, chemi-



THE CYCLE OF ROCK CHANGE

Modified from Shimer.

cal, and physical change, becoming transformed, or, as the geologist says, metamorphosed: sandstones go over into harder quartzites, limestones are transformed into marbles, mudstones become slates or schists, granite and other igneous rocks are made into gneisses. Similar changes may occur when rocks are subjected to great pressure in the process of being folded into mountain ranges.

Resting upon all these various rocks, and resulting

from their decay, is a very thin layer of unconsolidated fragments of comparatively recent making. This zone embraces all the loose materials of the lands, the soils, clays, sands, gravels, and boulders. Usually its depth is measured in a few feet, though in places it may be hundreds of feet thick.

We speak of the earth's crust as solid, but this does not imply that its constituents are in a state of stability. On the contrary, the rocks are constantly undergoing slow chemical change, due, first, to gravitational and tidal forces; second, to interactions among the rocks themselves; third, to reactions with the hydrosphere or water; and fourth, to contact with the atmosphere. Under the second division come the changes that molten rocks undergo as they ascend from the interior of the earth through the cold and solid higher rocks, and the effects they produce on the latter; under the third are the effects produced by water as it washes over the surficial rocks or percolates through the deeper lying ones; and under the fourth, the changes wrought by air in contact with rocks or soil. The last two processes are grouped together under the term weathering.

FRACTURES IN ROCKS, ENLARGED BY RAIN AND FROST

After Johnson.

CHAPTER III

THE LOOSE MATERIALS OF THE EARTH'S SURFACE

WE have seen in the last chapter that the topmost layer of the lands is made up of the loose material derived from the solid rocks beneath, now lying piled up on the surface as soil. It is a commonplace to us that this loose rock material is not spread evenly out over the country, but is thinnest over the land as it rises into hills, and thickest in the valleys. If the climate is a humid one, then the land is also clothed with vegetation and even with forests, and in all the valleys there are flowing streams of water. Accordingly the rocky framework of the earth is often invisible in such regions, but a little closer search shows that along the bottoms of the streams and in places along their sides the solid rocks are ex-

posed, as they are even in greater degree on the hillsides. The more hilly the land, the more the rocks show, and the mantle of soil in the little mountain valleys becomes more and more rocky as one ascends. The higher one goes into the mountains, in fact, the more the solid earth sticks out, and the larger and more angular are the broken-up rocks.

Here, as everywhere, the hardest of rocks are breaking into pieces, small and large, which will eventually roll down the precipices and come to rest in the hollows or on the lower slopes of the ridges. Their resting period is, however, never a protracted one, since the atmosphere and other destructive influences keep on breaking them smaller and smaller, until rain and gravity carry them to lower and lower levels down the mountainsides and finally along the stream courses. This making of soil, sand, dust, and mud is the result of the process of erosion, which in geology means the wearing or gnawing away of the rocks by the atmosphere, wind, water, and other physical and chemical interactions.

The climates are by no means everywhere wet ones, however; in fact, one-fifth of all the lands are deserts, and this means that they have a marked deficiency of rain. With this lack of moisture, it follows that vegetation is more or less scarce or even wholly absent. Accordingly one sees in the rugged parts of these areas far more of the solid earth than elsewhere, although in the valleys and plains there may be immense accumulations of loose rock. In some of the deserts all of the finest rock powder is blown away, while the coarser sand is rolled along the ground to make the hills of wandering sand called dunes.

This mantle of soil which nearly everywhere envelops the lands has a very great significance for us human beings, since it is here that the extraordinarily varied plant world upon which the entire animal kingdom is dependent has its rootage and gets its water. From the air the plants obtain carbonic acid for their actual sustenance, and through the energy of sunlight and the water of circulation within the plants this carbon is changed into starch and sugar, wax and honey, wood, seed, and cereal. Hence without plants there could be no animal life, and naturally no human beings; the plant world is, indeed, the producer of the organic energy that the animal world takes, along with oxygen and water, and spends in the upkeep of its existence. It is of interest, therefore, to see how this mantle of loose and fragmented material, which affords growth-area for the plants, has come to be.

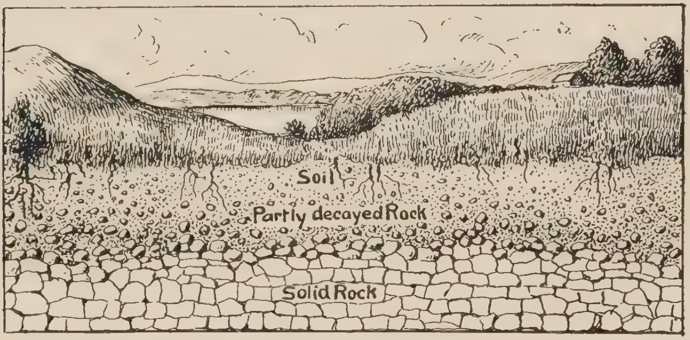
Ever since the earth has had a cold rocky surface and a sunlighted atmosphere, the crust has been subject to ceaseless change because of the internal chemical reactions between the circulating water and the rocks and between the rocks themselves, and because of the external wearing produced by air and water. The latter, the so-called weathering influences, act very slowly, but as geological time is exceedingly long, the work of the moment will eventually aggregate very large. In this way one mountain chain after another has been fragmented and dissolved, dragged down piecemeal by the waters of the rivers and by the winds, and delivered into the seas and oceans, there to be spread out by the waves into the tens of thousands of feet of stratified rocks.

The atmosphere works both chemically and mechanically upon the rocks, changing their constitution and frag-

menting them; and when the dust-laden air is in decided motion, it also helps to wear them down. The chemical action of the air is greatly increased in the presence of rain water, and especially in warm climates, while the mechanical effect of fracturing is enhanced by marked temperature changes. All materials expand more or less on heating, and shrink on cooling, and since the rocks are composed of mixtures of different minerals that expand variably, it follows that their outer parts are constantly under varying stress. This variability of expansion and stress quickly leads to minute fracturing and eventually to deep cracking and jointing, such as may be seen on any exposed rock surface, and the cracking is still further accentuated by the expansive power of freezing water, especially in the high mountains.

Into all of the rock fractures, however minute, the air and water enter with their dissolving powers, ever increasing the areas of chemical and mechanical change. Pure water itself is a solvent of rock, but rain also carries in solution oxygen and carbon dioxide, both of which act chemically on the rocks. Some of the rock substance is therefore dissolved by the rain waters; other portions are partly hydrated, i.e., take into combination some water; oxygen converts the compounds of a low state of oxidation into those of a higher; and carbon dioxide, with the water, helps to bring substances into solution and changes them into carbonates. In this way the flowing waters take away materials in solution, or float off the lighter clays and silts and sands. Fracturing, solution, hydration, disintegration, and mechanical sorting are, then, steps in the process of rock decomposition and the making of soils.

Plants also help greatly to decompose rocks, both mechanically and chemically. Their roots, while still minute, penetrate the rocks and soils and, expanding with growth, aid to break them smaller. The roots often contain organic acids, like citric acid, and these react on the rocks; besides this, the plants take out of the soils mineral matter, such as potash, to be returned in a changed form when they die.



CHANGE, THROUGH WEATHERING, FROM SOLID ROCK TO SOIL
After Tarr.

Certain bacteria, feeding on the nitrogen compounds that the rain brings out of the air, convert the ammonia into nitric acid, and this eats into the calcareous parts of rocks. Other types of micro-life likewise bring about decomposition of organic matter and generate carbon dioxide. Some of the animals are also very great factors in the breaking up of soils, for instance, the ants, mice, and other burrowing types. Preëminent in this respect, however, is the ubiquitous earthworm, which eats the soil, digests out of it the decaying vegetable matter, and de-

A STREAM OF ROCK WASTE OR TALUS
Tower of Babel, near Lake Louise, British Columbia.

posits the undigested portion in little irregular piles as castings, in this way "giving a kind of under-tillage to the land, loosening the soil, and rendering it more permeable to the air." It was Charles Darwin's book *Vegetable Mould and Earthworms,* first published in 1881, that brought to our attention the important work done by this world of groveling animals; as Alfred Russel Wallace has well said: "Darwin elevated one of the humblest and most despised of the animal creation to the position of an important agent in the preparation of the earth for the use and enjoyment of the higher animals and of man."

The loose rock material of the earth's surface is very variable in size. When the pieces are larger than melons they are called boulders, those larger than peas make gravel, the sand (quartz) is known to all, while the finest material is dust, mud, or clay. Loam, the most easily tilled soil, is a mixture of sand and clay. The red and yellow colors of soils are due to the presence of iron, while black or humic soils have much decayed vegetation (carbonaceous matter).

So far we have been dealing with soils made in place, that is, made directly from the solid rock beneath them, but soils are often found at a considerable distance from their place of origin. In other words, a second process to be studied in connection with soils is their distribution or transportation. At the base of a cliff, or a mountain precipice, the fallen rock accumulates in heaps that are known as talus. In the same way, the soil is deepest at the base of the hill, whither it has been washed from above. In a river trough, the loose materials have been transported and deposited by the stream, mainly in times of floods; the muds, sands, and boulders that form the

so-called alluvial soil may have come tens or even many hundreds of miles. The glaciers in the mountains bring down to lower levels immense quantities of rock, ranging in size from that of a small house down to the finest muds. Moreover, at times when the earth undergoes cold climates, great ice-sheets form to depths of thousands of feet, and move slowly hundreds of miles toward lower and warmer areas, then, again, melting completely away, leave the land covered with a rocky débris, the so-called drift—the glacial clays, moraines, etc., of the geologist. Therefore the loose materials of the earth's surface, while largely formed in place, over great areas consist of material transported thither by rivers, winds, glaciers, or continental ice-sheets, in ways that are discussed further in succeeding chapters.

CHAPTER IV

RAIN, RIVERS, AND VALLEYS

RUNNING WATER, THE MOST POWERFUL EROSION AGENT

THE previous chapter has shown how the rocks of the earth's surface are broken up, decomposed, and made into soils mainly through the weathering influences. In this condition they are subject to easy transport by water; as John Fiske has well said: "All over the globe the myriad raindrops rushing in rivers to the sea are with tireless energy working to obliterate existing continents." In fact, the whole of the loose material and even the hard rock of the earth's surface is in slow motion, geologically speaking, toward the lowest places, the seas and oceans, where they come to rest in the layers or strata known to geology as the stratified rocks.

As rocks are of unequal solidity, some very soft, others crumbling easily, still others very hard and resistant to the weathering influences, it follows that the wear and tear on the land is very unequal. Mudstones (shales and clays) in horizontal beds are the softest of rocks and

soon wear away, giving rise to verdure-clad valleys and lowlands. Sandstones are much harder, especially if the cementing material that binds the grains together is not easily soluble, and limestones with much sand are also very resistant. Pure limestones in warm humid climates dissolve away rapidly, but in dry climates they are hill and ridge makers. When any of these kinds of stratified rocks are compressed and folded into mountains they become harder, and when further subjected to heat and pressure because of intruding igneous masses, they grow still more resistant. Finally, the hardest of rocks are the basalts and granites that have frozen out of molten magmas. Under these conditions, and in view of the further fact that the amount of rain, heat, and vegetation is very variable from place to place, it follows that there must be very different rates of rock wear and rock removal over the land surfaces. Here, then, is the reason for the sculpturing of the lands into hills, valleys, and plains.

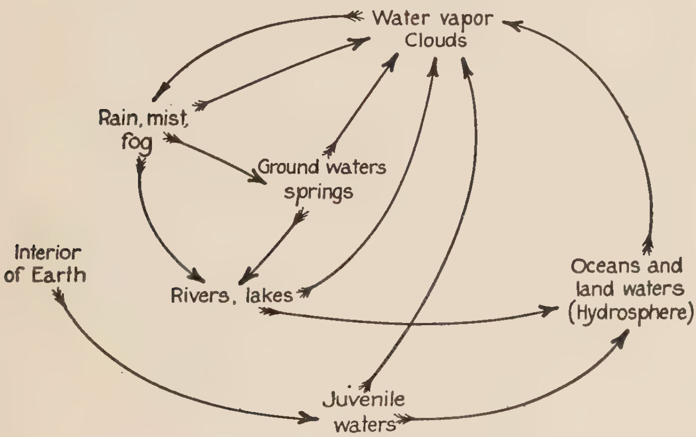
As rain is the most important agency in the leveling of the lands, and as even in the deserts the transporting power is water and wind, it is well to look a little into the causation and distribution of rainfall. We have seen that the rain of the lands comes from the oceans, and that sunshine heats and moves the air, causing the winds to bring moisture to the lands. There are, therefore, three great factors making for rock removal and life production, namely, sunshine, temperature, and water-vapor. Without rain there can be little removal of rock, and no life, and without sunshine there can be no rain.

The rainfall of the world is very unevenly distributed; in tropical regions, where "the rain it raineth every day,"

VARIATIONS IN ANNUAL RAINFALL

Areas of excessive precipitation (over 80 inches), black; abundant (40-80), ruled; sufficient (20-40), dotted; scanty (under 20), blank. After Jefferson, in *Geographical Review*.

the annual precipitation is over 80 inches, while arctic lands get 10 inches or less. A very great part, but by no means all, of the water-vapor raised by the sun out of the oceans falls upon the lands, and here much of it is again and again vaporized and redistributed as rain, but in the end nearly all the water is returned to the oceans by the rivers. Because of this circulation of moisture the



THE CYCLE OF WATER

Juvenile waters are those rising out of the earth's interior as a result of chemical changes and consequent volcanic activity.

amount of rainfall that any country may get is dependent upon several factors. These are: temperature, the directions of the prevailing winds, and whether these move over low lands or rise over high and cool mountain ranges. Accordingly the rainfall is very variable over the parts of all continents. For instance, water-laden air currents flow northward from the Gulf of Mexico and landward from the northern Atlantic as well, causing the eastern

portion of the United States to get more than 40 inches of rainfall each year; in the Mississippi Valley and northeastward across Labrador, the amount averages around 30 inches; while over the high and colder Great Plains it is 20 inches or less, and hence this region is semiarid. West of the Rocky Mountains the land is in general deserts, having a rainfall of 10 inches or less, though in

RAPID SOIL EROSION, AFTER HEAVY RAIN

Such erosion is much accelerated when there is no vegetation present to bind the soil more firmly together. After Gilbert.

the proximity of high mountains there is more rain because mountains are great cooling condensers of moisture. Along the high and rugged Pacific coast there is again far more rain, locally from 20 to over 60 inches each year.

Of all the rain that falls, about one-fourth constitutes the immediate run-off, which makes the freshets

A YOUNG VALLEY

The Yellowstone Park region, now 8,000 feet above the sea, was up-lifted in comparatively recent geologic time; hence, although the rapid Yellowstone River has cut this marvelous steep-walled canyon to a depth of 1,500 feet, the slower weathering influences have not yet had time to bevel back its walls.

and floods in the rivers. Some of the rain of each storm is again evaporated into the atmosphere, but the greater part soaks more or less deeply into the ground, becoming the ground-water, and giving rise to seepages and springs, which in turn serve for the maintenance of the rivers and the innumerable wells dug by man. Another part of the water, soaking still deeper within the fractured and porous rocks, supplies the artesian wells. Indeed, there are

MEANDERS

The Bighorn River, where it crosses the plains of Montana. After Darton.

vast amounts of rain water stored in the rocks, even in those beneath many of the deserts.

The run-off of the rain gathers in tiny rivulets which run together to form brooks and creeks and eventually find their way into the constantly flowing rivers. Rivers are the trunk drainage lines, and, furthermore, are transportation systems, since they are burdened with the waste

of the land, which they finally deliver to the seas and oceans. This load is carried partly in suspension, partly in solution, and the larger and heavier material is rolled along the bottom.

In addition to transporting the waste of the lands, the rivers have another important geologic function, that known as corrasion or downcutting. A river, says Pro-

AN OLD VALLEY

The Ohio River, shown here at Parkersburg, West Virginia, is a very ancient one, going back to early Mesozoic time, hence the rounded depressed hills and the very wide valley. The low-lying plateau which it crosses was reëlevated a few hundred feet in recent geologic time (Pleistocene), causing the river to quicken its flow and to cut deeper into the rocks, thus making the steep banks.

fessor Pirsson, "may be compared to a sinuous, flexible, and endless file, ever moving forward in one direction, and by means of the moving sand and gravel rasping away the country rock beneath and beside it, thus cutting an ever deepening trench." Most of this wearing-down action of the rivers is done in the highlands, where their grade is steepest, and the water moves fastest. Accordingly the river troughs here are often narrow V-shaped gulches and canyons with steep walls; they are said to be in the youthful stage of river evolution. Gradually

A GATEWAY THROUGH MOUNTAINS, CUT BY A RIVER WHEN ITS GRADE WAS STEEPENED

The beautiful Delaware Water Gap, worn by the river through the hard Silurian conglomerates of the Kittatinny Range. Note the flat skyline of the plateau, once near sea-level. Photograph by the U. S. Geological Survey.

the walls are beveled back by weathering and the run-off, the trough becomes more and more widely U-shaped, and the river is said to be in the mature stage. Finally, in old age, when the highlands are gone, the troughs are very wide and shallow and the rivers meander in great curves from side to side, widening their courses rather than deepening them.

The trough of a river includes the stream itself, its flood-plains, and all that is bounded by the bluffs between which it flows. A gorge is a narrow and deep trough without flood-plains. The term valley, on the other hand, refers to the wider depression in which the trough or gorge lies, and a basin includes the area drained by a river or a river system like the Ohio or the Mississippi.

Throughout the history of a river it cuts down or corrades in the highlands, but in the lowlands it may reverse the process and aggrade or build itself up, especially in times of flood, when it piles up sandy clays over its flood-plain. Finally, some rivers build themselves far out into the sea and form great deltas or fan-shaped headlands, such as that of the Mississippi River, which began long ago at Cairo, Illinois, and now extends out into the Gulf of Mexico far beyond New Orleans. (See figures on pages 52 and 57.)

The chief geologic functions of rivers are, then, first, the sculpturing of the land, and second, the removal of the resulting waste. This interaction of land and water has gone on throughout the geologic ages: mountain ranges as high as the Rockies have been worn down to their roots, and out of the level surfaces of high plateaus has been chiseled a labyrinth of gorges a mile deep and

ten miles wide like that of the Grand Canyon of Arizona. Such work of destruction of course results in an enormous amount of rock waste, which the river, like a good workman, proceeds to remove. The total amount thus removed from the lands is almost too tremendous to grasp. The Mississippi alone delivers annually to the Gulf about 340,000,000 tons of mud or silt carried in suspension, about 136,000,000 tons in solution, and about 40,000,000 tons of sand rolled along its bottom. In other words, the annual load of the "Father of Waters" is about 516,000,000 tons, which, if gathered together, would form a right-angled prism with a base one mile square and a height of 250 feet. The Ganges empties into the Bay of Bengal an annual burden of 356,000,000 tons of silt. Probably the most active of these levelers of the continents, however, is the Yangtze-kiang, which carries to the sea annually, according to Fabre, "three times as much matter as the Ganges. For conveyance of this immense mass of silt there would be required a fleet of two thousand ships, each with a capacity of 1400 tons, and they would have to descend the river daily and throw their cargo into the sea."

Not all rivers, naturally, wear down the land at the same rate, the differences depending upon the amount of rain, the hardness of the rocks, and the steepness of grade. It has been estimated, however, that the United States as a whole is being lowered roughly at the rate of one foot in about 7500 years. At this rate it would take 15,000,000 years to reduce it to sea-level, but as erosion goes on more and more slowly as the slope is reduced, the time required would in reality be enormously greater.

When plains are raised into plateaus, all their streams are revived or rejuvenated, because the grades are steepened, causing them to corrade more rapidly and again to cut young and steep-sided gorges. If the elevation of the land is considerable, then the old meandering rivers will entrench themselves deeply, maintaining their previous courses; such are said to be entrenched rivers, of which the Potomac, Delaware, and Susquehanna are good examples. On the other hand, when the land is elevated athwart the old stream courses through folding or faulting, some of the rivers will maintain their original direction by cutting through the rising elevations, so slow is the rising of mountains. The streams are then said to be antecedent, because they are older than the elevation through which they are now cut, the Hudson River being a good example of this type.

CHAPTER V

THE HUDSON AND MISSISSIPPI RIVER SYSTEMS

RIVERS, as we have seen, have been one of the active agents in carving out the scenery that lies about us, and their geologic importance and long history are therefore unquestioned. They have always, moreover, been of even greater significance in the everyday life of man, and their history is constantly interwoven with his. Waterways: whole volumes of man's history might well be written from that angle, beginning with the day when he first discovered the ability of wood to float and bear a burden downstream. The early records of explorers on this continent are tales of canoe trips along our great rivers, and even when they came to the apparently impassable mountains, it was through passes cut by rivers that they pushed their way. Then, with the thickening of population, the rivers were used more and more as arteries of commerce, until cities grew up on their banks and great seaports came into being where they reach the sea.

With this dual importance of rivers in mind, it will be interesting to learn something of two of our best known river systems—two whose characters are very different, as determined by the nature of the country through which they have had to establish their way, and both of which have played a striking part in our history and continue to hold a notable position in our transportation system.

The first of these great rivers, the Hudson, arises high in mountains, descends rapidly to sea-level, and then, curious as it may seem, flows at this level through an old mountain system out into the Atlantic Ocean. The other, the vast Mississippi River system, is a very complex one which originates in a plains country, continues to flow for thousands of miles through lowlands, and receives on its way to the Gulf of Mexico hundreds of tributaries coming down from both Appalachian and Rocky Mountains.

The Hudson in colonial days was known to mariners as North River, to distinguish it from South River, the present Delaware estuary. To New Yorkers, moreover, it still remains the North River, while the estuary on the other side of Manhattan Island is their East River, leading inland through Hell Gate into Long Island Sound. The North River was first seen by Verrazano in 1524, but it takes its other name from Henry Hudson, an Englishman in the service of the Dutch East India Company, who in 1609 sailed his twenty-ton vessel, the *Half Moon,* up to Albany between September 12 and 18, and had the journey recorded in the ship's log by his mate, Robert Juet. The Hudson was also to see the birth of steam navigation one hundred and ninety-nine years later. During the Revolution, the mountain belt of the Highlands, between Peekskill and Cornwall, played its part

THE HIGHLANDS OF THE HUDSON

Looking upstream, West Point at the left. Photograph by the New York City Board of Water Supply.

in the political fate of the Colonies by affording to General Washington the easily defended strongholds of Newburgh and West Point.

The birthplace of the Hudson is Lake Tear of the Clouds, a small tarn high up on the south side of Mount Marcy in the Adirondacks. Leaving the lake at an elevation of 4320 feet, the river rapidly descends the mountain, flowing over some of the oldest rocks anywhere known, through many ponds and over numerous cataracts and waterfalls. It is a clear-water stream, because of the hardness of these old rocks, and in 100 miles it drops more than 4000 feet, descending in the next 50 miles to sea-level at Albany.

A few miles to the north of this city the Hudson's largest tributary, the Mohawk, comes in from the west, descending in a broad depression between the Adirondacks far to the north and the foothills of the Catskills on the south. Above Albany there are eight other tributaries, and below the capital city twelve more, making the whole of the Hudson basin drainage 13,360 square miles.

From its beginning in the Adirondacks until it reaches the city of Albany, the story of the Hudson is that of a highland river, beginning with a swift descent from the mountains and then turning due south in an old open valley. At Albany, however, having reached sea-level, it begins to feel the influence of the tides setting back from the ocean 150 miles away. For the rest of its course, the average width is about a mile, although south of Poughkeepsie it is a mile and a half, and at Haverstraw, south of the Highlands, it widens to four miles. In many places along both shores there are more or less

long marshes replete with vegetation. Accordingly the river looks as if it were in flood, and yet the water is devoid of mud. Twice each day the tide flows inland, and as often toward the sea, but there is no strong current.

Below Albany, as seen from the deck of one of the palatial Hudson River steamers, the river continues for some distance in the same open valley, with no marked relief features immediately on either side. The appearance is that of a lowland, but it is in reality the roots of the ancient Appalachian Mountains, which have been worn down here into an undulating and deeply dissected plateau, though the record of this in the crumpled rocks can be read only by the geologist. The first marked break in the western skyline comes with the storied Catskills, home of Rip Van Winkle, which have escaped the ravages of erosion in large measure because of the many hard sandstones and conglomerates protecting their rounded summits. They rise to 4000 feet above the sea, are heavily forested, with rather abrupt slopes on the side toward the river, and their soft blue outlines are visible as far down as Poughkeepsie.

Nearly all rivers have elevated terraces along their banks, which mark former higher levels of the water. Along the Hudson north of the Highlands these are as a rule not easily seen, although in winter the snows make them plainer. There are, however, conspicuous rock terraces within the Highlands, ranging between 150 and 350 feet above the river, on one of which stands West Point.

North of West Point, the Hudson has no particularly unusual characteristics, but its lower reaches present some

remarkable features that have long puzzled geologists, since it has worn itself grain by grain diagonally through the very heart of the central Appalachians, the so-called "Highlands." Passing West Point, on the west Storm King rises abruptly to 1340 feet; across the river are Breakneck at 1635 feet and Beacon Hill at 1635; guarding the southern gates are Dunderberg (1150) and Anthony's Nose (900). These are parts of the granitic core of a once far more majestic range, a member of the great series that together make up the Appalachian System, stretching for 2000 miles from Land's End at Gaspé, Quebec, to central Alabama. The granitic Highlands of the Hudson, 16 miles across, are remnants of the central core of this system; the rocks to the northwest, however, are bedded sediments that originally were laid down in a horizontal position in the sea, but were long ago raised out of Neptune's realm and shoved together into the closely pressed folds that geologists now see, although, being less resistant than the granites, their mountainous elevation has disappeared.

The Highlands appear from the surface of the river to be a range of rugged mountains, yet when we ascend to their tops and look about, the scenery is that of a plateau. Of course it is deeply cut into by the rivers, but nevertheless this upper surface is an elevated plain which extends far to the southwest through New Jersey and Pennsylvania. Geologists speak of mountains thus worn away and leveled down to a plain as rump mountains, and when the plain is subsequently elevated hundreds or thousands of feet above sea-level, it becomes a plateau. The old Appalachian plateau is described further in the chapter dealing with plains and plateaus.

The region around Storm King is of special interest because of its connection with the great aqueduct that brings water from the Catskills to New York City. This water, from a number of streams, is impounded and aërated in the beautiful Ashokan reservoir, not far from the region so beloved by John Burroughs, and is brought thence in tunnels to Storm King, where it enters the greatest siphon in the world. The tunnel here goes beneath the river, and as it has to be in solid rock to withstand the great pressure of the water, it was blasted through the ancient granites 1100 feet beneath sea-level. The siphon is 18 feet in diameter and about 3000 feet long where it ascends in front of Breakneck on the east side of the river. In making this siphon, an interesting fact was reëmphasized; namely, that the granite is free of percolating water, or, in other words, is dry, showing that the surficial waters and those of the Hudson have not percolated to the depth of 1000 feet, and justifying the conclusion that the amount of ground-water in the rocks beneath the surface has been much exaggerated.

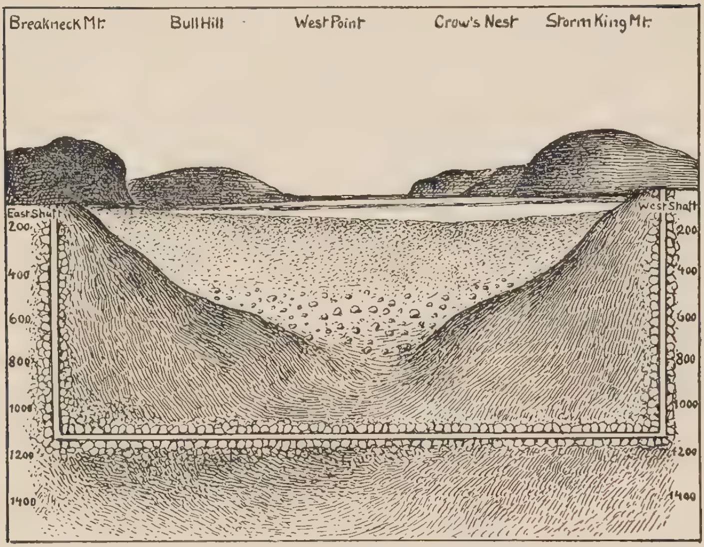
South of the Highlands the river widens into Tappan Sea, four miles wide and three times as long, a most beautiful and intricate waterway, requiring careful navigation. It is replete with legends, and their maker, the immortal Washington Irving, sleeps in the churchyard at Tarrytown on its shores:

> Here lies the gentle humorist, who died
> In the bright Indian Summer of his fame.
> A simple stone, with but a date and name,
> Marks his secluded resting place beside
> The river that he loved and glorified.

PALISADES OF THE HUDSON, A WALL OF SOLIDIFIED LAVA

This once molten rock spread out laterally between beds of sandstone, deep within the earth, to be exposed later when the softer sandstones above were worn away. Such cooled lava flows, with their characteristic columnar appearance, are also to be seen in East and West Rocks in Connecticut, the Devil's Post Pile in California, and the Giants' Causeway in Ireland.

From about eighteen miles north of New York City, the west bank of the Hudson is marked by the even-topped, pillared, and rusty-looking Palisades, which form the high eastern cliffs of New Jersey. The rock columns that produce the palisaded effect were shaped by vertical jointing when the rock of which they are composed, welling up from the depths of the earth as molten magma, cooled deep within the bowels of a massive series of red sandstones. These red sandstones may still be seen in northeastern New Jersey, but they formerly extended many miles farther east. Here, however, they have long since been worn away, exposing the columns of solidified



PROFILE OF THE HUDSON, AT STORM KING, LOOKING DOWNSTREAM

Note the deep channel or inner gorge, now filled with glacial material, which made it necessary to sink the shafts for the siphon of the Catskill aqueduct below 1,000 feet in order to keep within bed rock. After Kemp.

magma and laying bare the old floor upon which the sandstones once lay throughout western Connecticut—truly an old floor, since its rocks are of the oldest on the face of the earth.

Aside from the scenic features that delight the traveler, the bed of the Hudson also has an interesting story to tell. That the river lies in a gorge is not unusual, but what is remarkable is that it has over part of its length a second narrower channel below the first one, now filled with glacial rock débris. At Storm King, as shown by the borings made for the aqueduct crossing, this inner

gorge is abnormally wide, and, curiously, has a depth of over 750 feet, all of which is below sea-level. Moreover, it can be traced out into the ocean for 100 miles beyond Sandy Hook, where the river is thought at one time to have entered the sea over a majestic waterfall. The reason for these unusual conditions lies in the geologic history of the region, which is too intricate and as yet too little understood to be set down here.

The Mississippi is the largest of North American rivers, and, in fact, one of the largest of the world, being exceeded in length only by the Nile and in volume of water only by the mighty Amazon. The name is of Algonquin origin and means "great river" or "father of running waters." The river itself has been said to be the "most valued natural possession of the American people"; its source has been a dreamland for poets, and its delta, in the days of Spanish and French ownership a haven for buccaneers, has long been a field of inspiration for geologists.

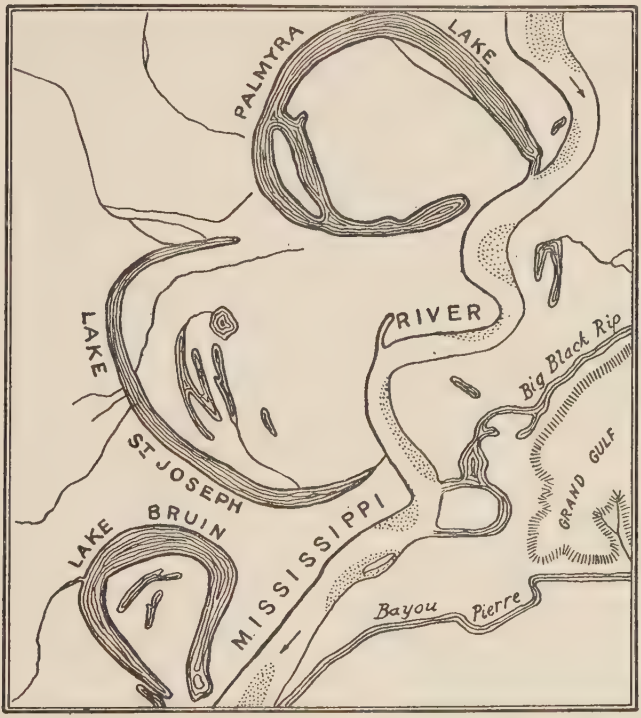
At first thought one might consider the Mississippi as the most important stream, commercially speaking, in the United States. It is, indeed, navigable for large steamers and barges at all seasons from the delta to St. Louis, and for smaller boats most of the year to St. Paul, 2000 miles from its mouth. Nevertheless in commercial importance among our inland waterways it is exceeded not only by the Great Lakes, but by the Erie Barge Canal and by the Hudson and Ohio rivers. One difficulty with the Mississippi for commercial purposes is that it flows in the wrong direction! If it flowed eastward from the heart of the United States to the Atlantic seaboard, say Huntington and Cushing in their *Modern*

Business Geography, it might be one of the busiest rivers in the world.

The Mississippi is so long that it was discovered in sections. The Spaniard, De Soto, coming upon the river at Chickasaw Bluff, May 8, 1541, called it the Rio Grande, and in the following year his party navigated it from the mouth of the Arkansas south into the Gulf. Two Frenchmen, Groseilliers and Radisson, apparently discovered the upper portion near Prairie du Chien about 1665 and explored it northward to above Red Wing. The men who actually made the great river known, however, were Joliet and Père Marquette, who in 1673 passed through the Great Lakes and like their predecessors went down the Wisconsin River into the Mississippi, and thence south to the mouth of the Arkansas, discovering on the way the mouths of the Missouri and the Ohio. Nine years later La Salle passed down the river to the Gulf and took possession of it and the country surrounding it in the name of the King of France, christening it Louisiana. The United States purchased these rights from Napoleon in 1803, while he was in trouble with England, for sixteen million dollars, thereby securing possession of the Mississippi from its source to the sea, and adding to our country a territory twenty-six times as large as the state of New York.

Schoolcraft, on July 13, 1832, thought that he had discovered the source of the river in a lake in Minnesota for which he coined the name Itasca, but the land here is so swampy that the actual source was later on seen to be in Little Elk Lake, 7 miles beyond Itasca. Minnesota is the watershed between Canada and the United States, with its highest land at 1680 feet. From this height of

land the drainage is eastward into the Great Lakes, northward into the Red River of the North, and southward into the Mississippi. Lake Itasca has an elevation of 1460



OXBOWS

These cut-off remains of former meanders are characteristic of the lower Mississippi. After Shaler.

feet, and from this point the Mississippi flows 2452 miles into the Gulf of Mexico. Contrast this with the Hudson, which drops 4000 feet in its first 100 miles!

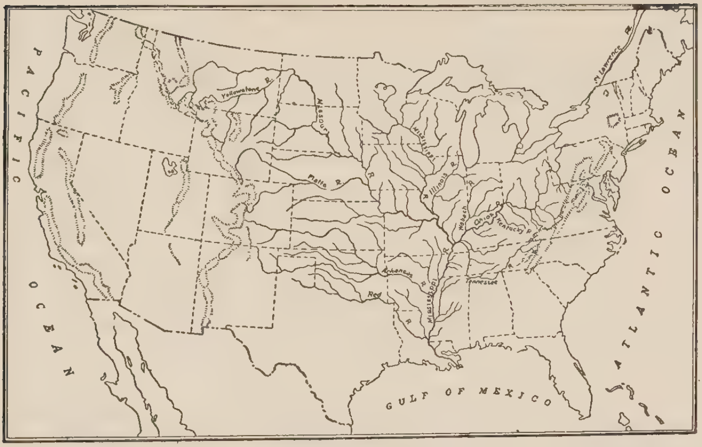
From Lake Itasca the course of the Mississippi is ir-

A PORTION OF THE MISSISSIPPI DELTA

From a mosaic of air photographs made by the U. S. Coast and Geodetic Survey.

regular, through a labyrinth of glacial lakes, with numerous rapids and small waterfalls in a land deeply covered with glacial drift. The first notable rapid and waterfall is that of St. Anthony at Minneapolis, with a drop of 80 feet. In the distance of 534 miles the river has descended to 683 feet at the head of navigation at St. Paul. From that point the course is more regular, and there are no natural obstructions except between Nauvoo and Keokuk, where there are rapids, and at Rock Island, where the rapids are 14 miles long with a drop of about 26 feet; in these places, however, there are now dams and power sites and canals for their traversing. The scenery from St. Paul to Keokuk is beautiful, and for 500 miles there are more or less high rocky bluffs, which run up to 600 feet below Prairie du Chien, the oldest town on the river.

At Cairo, Illinois, the river is 227 feet above the sea and it begins shortly to meander more and more widely from bluff to bluff in great oxbows through a series of "basins." Below Memphis, in fact, the Mississippi is said to be "the crookedest river in America." The Red River of Arkansas joins the Mississippi 300 miles above its mouth and in all the remaining distance the surface of the river descends only 3 feet, yet the flow is strong. The tides in the Gulf are from 1 to 2 feet, and go up the river 240 miles to Baton Rouge. There are in this stretch of the great river also a number of distributaries which aid in carrying off its surplus water in times of flood. In southern Louisiana the river course is again straighter, and here it deposits more detritus than it receives, and in consequence has built up its banks by overflow, forming a broad, gently sloping ridge of dry land on either side, which accompanies the river through



THE MISSISSIPPI RIVER SYSTEM, DRAINING 40 PER CENT OF THE UNITED STATES

the adjacent swamps. Indeed, these higher alluvial lands, of great fertility, begin 38 miles above the mouth of the Ohio River and continue for 1100 miles to the Passes at the mouth of the Mississippi. These alluvial lands slope away on either side about 7 feet in the first mile, and then to 6 inches per mile farther inland. Of the nature of the great Mississippi delta we shall learn in a later chapter.

Before the days of man-made levees, the lower Mississippi during times of flood had a width of between 20 and 90 miles, and the area subject to flooding totaled about 30,000 square miles. Now these valuable lands are protected by 1570 miles of levees, and the width of the river in flood is reduced to about 5 miles, but its surface level is 10 feet higher than it would be otherwise. There may be more than one flood in a single year, but commonly they are a few to many years apart. The one of 1912 established a record, pouring into the Gulf at

the rate of 2,300,000 cubic feet per second, but as this book goes through the press, the greatest flood in the river's history is bringing unparalleled disaster to the states along its lower course.

The flood-plains of the lower Mississippi are cut by interlocking bayous and channels, navigable for small shallow-bottomed boats. They parallel the entire course of the river for a thousand miles through the highly fertile alluvial land, thus opening it to navigation, "a characteristic that renders the mighty American river different from any other in the world."

The tremendous Mississippi River system is composed of several hundred rivers, and nearly all of their waters come as water-vapor from the Gulf of Mexico, to which they are returned burdened with detritus and salts. This compound drainage basin occupies 41 per cent of the area of the entire United States, extending from the Appalachians to the Rockies, and from the St. Lawrence watershed to the Gulf of Mexico (1,217,700 square miles).

The chief task of the Hudson is to bear shipping; the Mississippi, in addition to furnishing a mighty waterway, makes an important contribution to agriculture in the soil which it transports and redeposits toward the end of its course, for the fertility of these alluvial lands appears to be inexhaustible. Farthest south, rice and sugar are grown in great abundance, and from 31° 30′ northward for five degrees cotton grows in double quantities as compared with the uplands. The flood-plains are estimated to have about 23,000,000 acres of productive lands, "the largest body of equal fertility known to geography," and a loss of one crop in five from floods still leaves the farmer a considerable gain.

The Missouri is the principal affluent of the Mississippi; in reality, the system should have been called the Missouri River system, for then the length of the river from source to Gulf would be about 4200 miles instead of 2452. The Missouri rises in part in the Yellowstone National Park, that "place of fountains" which sends its waters northeast into the Missouri and the Gulf of Mexico, southwest down the Snake River across Idaho into the Columbia and the Pacific Ocean, and south into the Green and Colorado rivers and thus into the Gulf of Lower California. Below the mouth of the Missouri, the Mississippi is a muddy, dark, yellowish stream because of the mud brought in by the tributary river, which flows for hundreds of miles through the dry plains country with its easily loosened soil. Ordinarily the Missouri has one part of mud by weight in one thousand of water, but in flood periods this is increased tenfold. The annual discharge of muds into the Mississippi by the Missouri equals 400,000,000 cubic yards, and it is about this amount that is delivered to the Gulf.

Nearly all the rivers of the Mississippi system are corrading streams, but one of the tributaries stands out as a conspicuous example of an aggrading one. This river, the Platte, is peculiar in that while it has a relatively steep and an extremely straight course, it is at the same time building up and thus elevating its bed. This seeming anomaly is due to its being, taking the year as a whole, an overloaded stream; that is, it receives far more sand than the waters can carry away. The Platte is subject to great fluctuations in volume; when the snows of the mountains melt, in May and June, the shallow river may be a mile wide and the sands are then moved

AN OVERBURDENED STREAM, BUILDING UP ITS BED WITH SAND

The North Platte in midsummer, at the Nebraska-Wyoming line. Photograph by the U. S. Geological Survey.

downstream, but during the greater part of the year its upper and central portions are almost or quite dry, flowing through a semiarid climate.

The largest eastern tributary of the Mississippi, and one that is commercially far more important than the master stream itself, is the beautiful Ohio. This river drains nearly all of the Allegheny Plateau from New York to Alabama, and the abundant rainfall of that region sends down through the Ohio one-fourth of all the water which the Mississippi contributes to the Gulf. The first white man to see the river was apparently La Salle, who descended into it from the Allegheny in 1670 and went down as far as the Falls of the Ohio at Louisville.

To his countrymen the Ohio remained La Belle Rivière, but the English immigrants, coming across the Appalachians about 1750, corrupted the Iroquois name Ohionhiio (beautiful river) into Ohio. To them, in their westward course, there was but one river, and that the Ohio, and on this river and its tributaries they built their new empire and spread their marvelous conquest. The region north of the Ohio became the Northwest Territory, while the Virginians coming up the more southerly tributaries founded the Southwest Territory, stopping their plantations at the river.

"Stone coal" was mined and burned at Pittsburgh at least as early as 1818, and less than a century later this city was shipping down the Ohio an annual tonnage of coal and manufactured iron amounting to over 90,000,000 tons, a single stern-wheeled steamboat being able to convoy downstream steel barges carrying enough coal and iron to load a freight train 11 miles long. As a result of this economical means of transportation, and the presence of an abundance of cheap coal, the Pittsburgh district produces one-fifth of the nation's pig iron, one-quarter of its steel, one-sixth of its glass, and one-third of its coke, together with many other commodities, bringing its total annual production above two billion dollars in value. Small wonder that farsighted Andrew Carnegie saw the Ohio Valley as "the workshop of the world!"

CHAPTER VI

WATERFALLS

UPPER YOSEMITE FALLS

RAPIDS and waterfalls are scenically interesting parts of rivers, and therefore, although their geologic significance is slight, we may pause a little to examine some of their characteristic features. Crystal clear water in motion, with its ever varying play of light, fascinates us wherever we see it, and nowhere more than in foaming waterfalls. Most of these are small, many of them drop filmy "bridal veils" during the summer only, and others pour down endless quantities of sparkling water. Curiously, nearly all the plunging waterfalls are of clear waters, and none of the great ones have continuously dirty water, for if they carried and rolled along abrasives in any quantity, there would be no precipices for the water to fall over, since they would all be cut away by the corrading streams. All waterfalls are destined to vanish, in any event, because

A WATERFALL CAUSED BY A VERTICAL BED OF RESISTANT LAVA

Lower Falls of the Yellowstone River, where it enters its Grand Canyon. The drop here is 310 feet, almost twice as high as Niagara.

of their corrasive nature, but this fate may be very long in coming.

A stream passing through a region of soft rocks will erode more rapidly than in one of resistant rocks, and its corrasion will be greater with increased grade. In the Ohio and Mississippi valleys, where most of the bedded rocks remain horizontal and consist chiefly of mudstones and soft limestones, erosion is rapid, as is seen in the usually muddy condition of the streams. In these rivers there are, therefore, but few rapids and only low waterfalls, and these occur where there are resistant sandstones or thick and hard limestones. In the New England states and eastern Canada, on the other hand, the bedded rocks have all been subject to the hardening influences of mountain making and in addition are abundantly intruded with granites and other very hard igneous rocks, and accordingly most of the streams here are replete with rapids and waterfalls. They are also almost invariably relatively clear, with soft waters, in contrast to the hard-water muddy streams of the southern Atlantic states and the great interior of the country.

Waterfalls originate in many ways. In the Niagara type, the hard rocks lie above softer ones in a stratified series, as discussed more in detail later in the chapter. The two beautiful falls of the Yellowstone are due to vertical bands of harder lava that strike across the stream at those points, while the Yosemite Falls owe their magnificent drop of 2400 feet to the deepening of the valley beneath by ice action. Falls may also result when a stream is dammed by obstructions of some kind, such, for example, as the flow of lava across the Little Colorado River, which gave rise to Grand Falls, or the hard

THE TWO MAGNIFICENT CATARACTS OF NIAGARA, SEEN FROM THE AIR

The American Falls on the left, Canadian or Horseshoe Falls in the distance Photograph by Dallin

travertine deposits built up by springs, which have made forty-four "dams" within a mile in Falls Creek, Oklahoma.

Niagara, the greatest of American cataracts, has had a long and interesting history. The Niagara River is a short one, with a reach of only 33 miles, but it is nevertheless a great stream, since it drains the surplus rainfall of the four upper Great Lakes, Superior, Michigan, Huron, and Erie. At Buffalo, "Queen City of the Lake," it flows out of Lake Erie at a height of 336 feet above Lake Ontario, forming the boundary line between Canada and the United States. For about 25 miles it flows gently over the surface of the land, since it has not had time to make a valley, and in this distance it descends only 20 feet. Then, striking harder, more sloping rocks, its pace quickens into the upper rapids, and it descends 52 feet to the brink of the Canadian Falls.

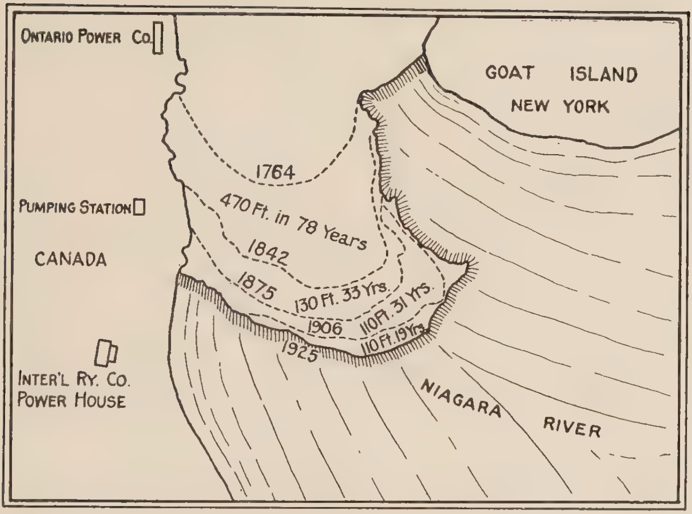
The original location of the falls was at Lewiston, seven miles beyond, but it has eaten its way back to its present site, leaving behind, to mark its path, the rocky Niagara Gorge, with a depth between 200 and 350 feet. In this gorge the lower river rushes and plunges and drops 100 feet, and finally goes quietly seven miles more across soft rocks into Lake Ontario. The very resistant dolomite (magnesian limestone) that caps the falls themselves may be seen making the upper cliffs of the gorge all the way to Lewiston.

At the American Falls, which has a frontage of 1060 feet and a drop of 167, this brink-making dolomite is 80 feet thick, and beneath it is a very soft formation of shale 70 feet in depth. If we descend the inclined plane nearby to the Cave of the Winds, we walk upon another and lower

limestone and then across the very stormy water-swept rocks to the undercut cave. High above is the bottom of the hard dolomite, while the inner wall is of soft and water-soaked shale. In winter time the water in this shale is frozen repeatedly, crumbling it and therefore making it all the easier during the summer for the winds and the swirling water of the falls to remove it piecemeal. This wearing away of the shale goes on year after year, until finally the capping dolomite, inadequately supported below and with the added pressure of the water above, falls in great masses into the depths of the lower river, there to undergo further destruction.

The actual plunge of Horseshoe or Canadian Falls is 158 feet, with a frontage along the curve of 2950 feet. This is the main fall, taking over 500,000 tons of water per minute, 94 per cent of the water of the river. The constant wear of this volume of water, falling from the great height, has dug out a very deep gorge 200 feet beneath the level of the waters, over which the tourist is taken by the *Maid of the Mist*.

How long has it taken Niagara to recede the seven miles from Lewiston to its present position? This is a very difficult question to answer because of the many unknown factors, the chief one of which is the variation in the volume of water with time. The first European to hear of the "Thundering Waters" of the Indians was the great French sea captain Cartier, and the time the year 1535. Father Hennepin saw the falls in 1678, when Fort Niagara was established at the mouth of the river, and he described it in 1683 and pictured it in 1697-98. His account of the place where the falls were in his time is so good that it has been relocated in modern times. And lo!



RECESSION OF NIAGARA SINCE 1764

"The [Canadian] Falls at which the tourist of to-day gazes are 150 feet farther along than when his father and mother saw them thirty years ago." At the American Falls, however, this recession is but a few inches a year, since they take only 6 per cent of the flow of the river. After a diagram made by the Niagara Falls Power Company, and reproduced in the *Review of Reviews.*

when the geologist, James Hall, first surveyed the region in 1842, he found that the falls had receded considerably since the time of Hennepin. Since Hall's day the falls have receded on an average 5 feet per year, and it is believed that this rate has been maintained for about 1700 years. Earlier the rate is thought to have been much slower. Some geologists have taken the annual rate of recession of the Canadian Falls as 2 feet, others as 4 and 5 feet, giving an age for Niagara of 18,490, 9,240, and 7,392 years, respectively. Probably the most satisfactory estimate is that of F. B. Taylor, who in 1913

concluded that the making of the Niagara Gorge took not less than 20,000 and probably not more than 35,000 years.

The highest waterfall in the world is Yosemite Falls in California. This beautiful fall plunges over a granite cliff into the Merced River Valley, with a first drop of 1430 feet, then cascades for 625 feet down a very steep slope, whence it takes the final vertical plunge of 320 feet to the flood-plain of the river, the usual entrance for tourists to the Yosemite National Park. The Merced Valley before the Great Ice Age was V-shaped, and then for a very long time a glacier slowly ground its way through it, deepening it greatly and abrading its sides into vertical cliffs. In this same national park are Nevada Falls, about 600 feet high, Vernal Falls with a vertical drop of about 300 feet, and Bridal Veil Falls which plunges 630 feet and cascades for 300 feet more.

CHAPTER VII

CAVES AS EVIDENCE OF SOLVENT WATERS

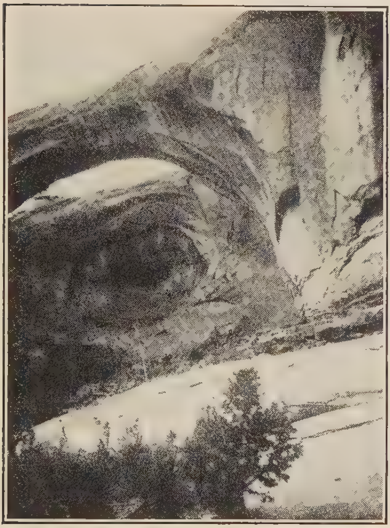


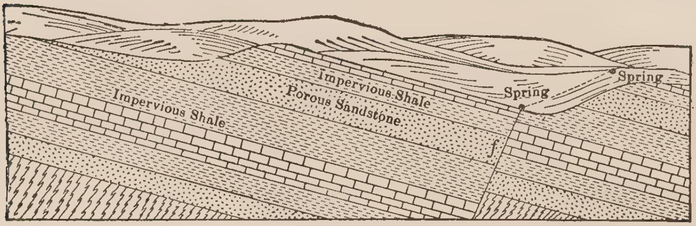
Photo by Bernheimer.

HAWKSEYE NATURAL BRIDGE

IN previous chapters we followed the work done by water on the surface of the earth, and now we must see what it does underground. Even when chemically pure, water is a solvent of many kinds of minerals and rocks, and becomes more so when as rain it takes up notable quantities of the carbon dioxide and oxygen of the atmosphere. Rain gives rise to vegetation, whose main sustenance is also taken out of the carbon dioxide of the air, and therefore when decomposition overtakes plants and animals, a part of them again goes back into carbonic acid. Accordingly, when rain water soaks through vegetation and soil, it becomes acidulated, and this is especially true in regions of wet climates where there is a great abundance of plant life, but even in the driest deserts

whatever water there is functions to some extent as a solvent of rocks.

Of the rain falling upon the earth, a part is evaporated and goes back into the air, another part runs quickly into the rivers and thence to the sea, and the remainder sinks into the soil and into the rock below it. This latter portion, the underground or ground-water, is of great economic significance, first, because it furnishes the sup-



CONDITIONS FAVORABLE FOR FISSURE SPRINGS

Surface water, sinking through the porous sandstone, is held there, in spite of its head, by the non-porous rocks above and below. When a fissure is encountered (caused, in this instance, by a drop of the strata on the left, known as a fault (*f*)), the water is forced upward to the surface. From Pirsson, by courtesy of Wiley & Sons.

ply upon which we draw for our wells, and second, because it is a distributor of ores, natural gas, and petroleum. It is, however, with its geologic function that we are mainly concerned in this chapter.

The underground water, percolating downward through the fissures in the rocks or through the pores between the grains of the soil, fills these up to a certain level, which is known as the water-table. The depth of this water-table below the surface varies as the seasons vary between wet or dry, or with the variation in annual rainfall; in dry

areas it may lie hundreds of feet down, below the soil and in the rocks themselves, but in wet ones it is usually within a few feet of the surface. When the surface of the ground intercepts the water-table, the water comes out as a spring; when the two surfaces coincide for some distance, the result is a bog; when the level of the ground sinks entirely beneath that of the water-table, we have a lake or river.

When the underground water soaks into a slanting rock layer that is porous but is hemmed in on either side by one that is not porous, it will be held there under pressure from the weight of the water-column behind. If, however, it encounters a fissure leading to the surface, it will be forced out through this channel and reappear as a fissure spring. Artesian wells, therefore, which supply the way of escape by boring, are merely artificial fissure springs.

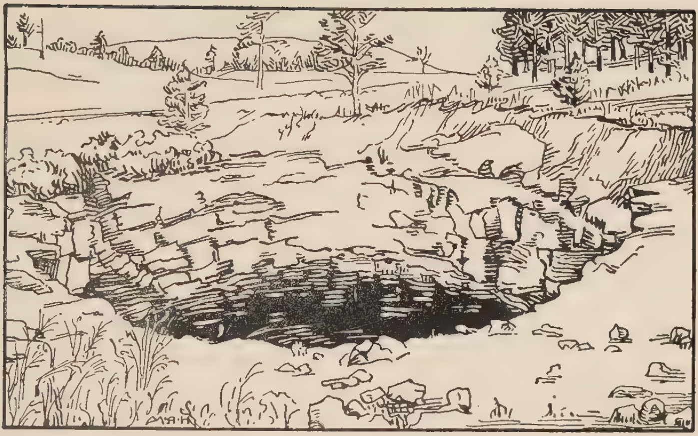
All of this circulating underground water is more or less charged with salts taken up in solution. Of these salts the more important kinds are the carbonates of calcium and magnesium, the sulphates of calcium, sodium, and potassium, chloride of sodium, and silica, all of which have been dissolved out of the rocks. The great solvent in this process is the carbonic acid in the water, which attacks the rock-making carbonates. Calcium carbonate, for instance, the chief component of limestones and the cement that holds together many other sedimentary rocks, is almost insoluble in pure water, but carbonic acid converts it into the bicarbonate, which is quite soluble. This destructive action of carbonic acid on carbonates is of great geologic importance, and it is the effects of such denudation that we are to discuss.

To visualize the amount of chemical denudation done

chiefly by rain water, we have only to recall that the Mississippi River delivers annually to the Gulf of Mexico about 136,000,000 tons of various salts, which means the removal through solution of 110 tons of matter per square mile over its entire drainage area. The annual average chemical denudation per square mile for the whole United States is estimated at 79 tons, and for all the lands the total is thought to be 2,735,000,000 tons per year.

In the great medial region of the United States and Canada, thick limestone deposits lie near the surface almost in their horizontal attitude of deposition. In the eastern and western mountains there are also thick formations of limestones, but here they are no longer in their original attitude of deposition, but have been pushed into great folds so that in places the strata now stand more or less vertical. Accordingly in the mountains the surface of attack of the acidulated waters is far less than in the intermediate plains. It is in the latter regions, therefore, under the humid climates, that we see the greatest amount of chemical denudation going on, giving rise to sinkholes and subterranean caverns. Through the cracks or joints in the surface rocks the waters work downward to the flat-lying limestones, enlarging their path as they go by dissolving out the calcium salts, until a pipelike aperture is formed, known as a sinkhole. If in their downward course they encounter an insoluble layer, the waters spread laterally, eating out the limestone below the surface into caverns, sometimes of enormous extent, and the process may be repeated until there are several superimposed galleries.

One of the best known areas for such phenomena is central Kentucky, which has, indeed, been called "the



SINKHOLE IN LIMESTONE

land of ten thousand sinkholes." Most famous of all its caverns, and the largest yet explored, is Mammoth Cave, and nearby there are said to be at least five hundred smaller ones. The limestone formation is 600 feet thick and is overlain by insoluble sandstone, which makes the roofs for all of the larger caves. Only when the roofing rocks have been worn away by other forces, or have fallen in because of lack of support from beneath, or where the sinkholes are free of dirt and tumbled rocks do the openings to the known caves appear. This collapse of the unsupported roofs of caves occasionally leaves a remnant of the rock standing in the form of an arch or natural bridge. Such bridges are, however, formed in several other ways.

Green River, the stream that controls the drainage of the region, both underground and surface, runs to-day in a channel 400 to 500 feet below the higher parts of the surrounding country, but in its work of cutting downward

through the rocks it apparently paused for a time at five different levels, and each resting stage is represented in the cave by a series of channels or galleries. The lowest of these superimposed levels is now about 300 feet below the original entrance, but as the river is still 400 feet above sea-level, at some future day the cave may be increased by the addition of still lower galleries.

The mouth of Mammoth Cave is 194 feet above the water level of Green River and less than one mile from it; its temperature is constantly at 54° F. Its avenues form a "bewildering labyrinth," crossing over and under one another and winding about in every direction, the main ones having a general course toward the river. The "rooms" are of various sizes up to 400 feet across, and 150 feet high, while the passageways vary in width up to 300 feet. Within the cave is Echo River with its small but highly interesting blind fish and crawfish. No cave, says Proctor, "approaches this one in size and sublimity of its avenues, its awe-inspiring domes, its mysterious rivers, and in the rare beauty of the festoons of flower-like growths and sparkling crystals that ornament miles of avenues."

Mammoth Cave is in limestones that lie horizontal. A group of smaller but very famous caves are situated in the heart of the folded Appalachian Mountains, the well-known caverns of Luray, one mile east of Luray in Page County, Virginia. Here the rock is a magnesian limestone and of much greater age (Ordovician) than that of Kentucky (Mississippian). The caverns of Luray are only some acres in extent, but are considered to be among the world's finest as regards beauty and variety of interior.

The same process that forms caves also tends to fill them up. Acidulated rain water percolating through the limestones becomes, as we have seen, charged with carbonate of calcium. Issuing from the rock and hanging crystal-clear in the dry air of the caves, it evaporates

STALACTITES AND STALAGMITES

"Totem poles" of dripstone in the Giants' Hall, Luray Caverns, Virginia. Photograph by the Luray Caverns Corporation.

water and loses carbon dioxide, leaving the calcium carbonate behind in the form of slowly accreting icicle-like stalactite and standing stalagmite, which may eventually become united. Elsewhere the water gathers on the roof of the caves in long sinuous lines of fracture, depositing

wavy and fluted translucent sheets which "hang like draperies and folded tapestries resplendent in a thousand hues." In fact, the forms taken by these stony growths are endless. There is a wealth of color but no great range, all a harmony of browns or gradations through yellows and whitish browns to the dun of the old and dried-out stalactite.

During the past tens of thousands of years, caves have been refuges, homes, burial places, and shrines for primitive man; and wild animals, especially bears, have lived in them as well. In this way came to be buried in their yellow flooring—the residual earths of the dissolved limestone—the bones of human beings, man-made stone implements, and the remains of wild animals. Then the caves became wet again and drip rock sealed the layer of cave earth. In some caves this alternation of entombing and limestone deposition has gone on several times, and now when such places are studied, layer after layer gives a most wonderful chronology of evolving man and his cultures. In southern France and northern Spain many caves must have been places of worship, since their walls and ceilings are decorated with line engravings and color paintings of animals, revealing to us creatures like the mammoth which have long since become extinct.

OPEN CUTS, UNITED VERDE COPPER MINE, ARIZONA

CHAPTER VIII

THE TREASURES OF THE EARTH

There is no substantial conception of property apart from the products of the rocks, the soils, the mines, the water, the air—and these in all their functions are geological factors.—JOHN M. CLARKE

CAVES represent one phase of the work done by the great body of waters that percolate into and through the rocks, but these same solvent waters have another task which affects us even more closely. This has to do with the storing up of the mineral wealth that lies buried within the earth's crust.

A little thinking will convince anyone that man gets his sustenance, his raiment, and his habitations out of the ground. In the soil, through the energy of the sun, inorganic matter is transformed into organic growth which man takes directly and indirectly for his meals, clothing, and building materials, while beneath the soil he finds a part of his water, his fuels, and his metals. Pre-

historic man, living in the Stone Age, made his implements and ornaments of stone, usually of flint, and after he had learned to quarry this material, used it as an object of barter; peculiar yellow flints from the French village of Grand-Pressigny (Indre-et-Loire), for example, have been found in ancient stations as far away as Belgium, Italy, and Switzerland. The use of clay for pottery also had its beginning back in the Stone Age. The discovery of the metals ushered in the Bronze Age, to be followed by the Age of Iron. In all probability gold was the first metal to be noticed, due to its color and its presence in gravels. It was, however, too soft to be usable in weapons and thus worthless except for ornaments, and not until early man had found copper ores and, by accident or otherwise, learned the method of extracting the metal from them, did metals come into marked prominence. There are evidences that copper was in use in Egypt as early as 5000 B. C. Iron mines of much earlier date are known, but the discovery of how to obtain the metal from the ores seems to have been subsequent to that in the case of copper.

Within historic times, as the need for minerals increased, the search for them has written some of the most romantic pages into the history of man. Rubies in India, gold and silver in Mexico, gold in California and Africa, iron in Alsace: these have set in motion caravans of exploration, made and unmade colossal fortunes, and had their parts to play in the very fates of nations. This comes about because the minerals are not evenly distributed, but occur only in very limited areas where nature has accumulated them. In fact, mineral deposits are "mere incidents in the mass of common rocks."

Useful rock materials, like gravel, sand, clay, sandstone, and limestone, have the widest distribution. Coal and iron in minable quantities are more restricted, and for marble, granite, and most of the metals we have to go to the mountains or the places where they once reared their proud tops. Until very recently the finding of valuable ores has been in the hands of the untrained prospector, but now he is being replaced by the trained prospector and geologist, who directs the engineer how to follow the ramifications of the valuable deposits. The finding of the decidedly localized valuable ores comes only through long searching, and even then a "bonanza" is the rare exception. Mining investments are, indeed, among the most precarious, and the profits of mining have been dearly paid for by the prospector, by the laborer, and by the enthusiastic investor. Yet in the ultimate it is all worth while.

The mineral wealth drawn from the rocks falls into two main groups, metals and non-metals. Most conspicuous in the latter group is coal, which "furnishes the strong muscles of a country." Without coal, water-power, and iron, a nation is a weakling, but with them it is a giant that can draw long trains of heavy cars, propel great steamships, and drive the machinery of huge factories. Coal and iron are at the basis of the present industrial evolution, and coal makes it possible for the largest number of human beings and the greatest workshops to be in the temperate zone. We are living in the Age of Machinery. The United States leads in mineral wealth, but among nations we are the spendthrift, wasting our inherited wealth to get quick results.

Despite its great rôle in the destinies of peoples, coal

VALUE OF SOME OF THE MOST IMPORTANT MINE AND QUARRY PRODUCTS OF THE UNITED STATES IN 1922

(*U. S. Geological Survey*)

NON-METALS	*Mineral Fuels* Value $2,730,000,000 *	Humic (bituminous) coal (408,000,000 tons)	$1,294,000,000
		Anthracite coal of Pennsylvania (49,000,000 tons) ..	273,000,000
		Petroleum (551,000,000 barrels)	900,000,000
		Natural gas value at wells ..	196,000,000
	Stony Products Value $931,000,000 *	Cement (from limestone and clay, 118,000,000 barrels)	208,000,000
		Stone for building, paving, flux, etc.	118,000,000
		Sand and gravel for building, glass-making, etc.) ...	64,000,000
		Clay (raw) for pottery, tiles, and refractory products ..	8,000,000
		Lime (3,528,000 tons)	33,000,000
		Slate (607,000 tons)	9,000,000
		Gypsum (3,900,000 tons) ..	17,000,000
		Salt (6,800,000 tons)	27,000,000
METALS, *Value* $985,000,000 *		Pig iron (27,670,000 tons) ..	608,000,000
		Copper (944,000,000 lbs.) ..	127,000,000
		Silver (55,500,000 fine ounces)	55,500,000
		Lead, refined (468,000 tons)	51,500,000
		Gold (2,375,000 ounces Troy)	49,000,000
		Zinc (353,000 tons)	40,000,000

* Including other materials not here mentioned.

is of rather humble origin, being the remainders of once living plants accumulated in swamps as peat, and finally buried under muds and sands. Second only to coal as a fuel, and already replacing it in many ways, is petroleum, "rock-oil," in the race for which America, England, and Holland are the leading competitors. As peat and coal,

however, are stratified deposits laid down in surficial waters, and as petroleum is largely the end-result of plant and animal decomposition, they are considered in more detail in the next chapter.

The term ore is often loosely used to designate anything that is mined from the earth for the uses of man, but not all things mined are ores or metals. Coal and petroleum, for example, are mined, but, as we have seen, they are of sedimentary origin and are classed among the non-metallic products, as are also building stones, cement materials, clay and sand, salt and gypsum. Therefore in using the term ores or metals we must keep clearly in mind such geologic deposits as yield gold, silver, copper, lead, zinc, iron, and dozens of other kinds of metals.

The metals occur in a great variety of conditions, and all of them came originally from deep within the earth. Molten rock or magma, rising from the deep interior into the zone of fractured rocks near the surface, was the agent that brought them within the reach of man, and it is in or near the cooled magmas, the igneous rocks, that he now finds most of them. There are three processes by which the metalliferous deposits originate: (1) the minute particles of metals that are carried upward by the magma combine with other elements to form minerals, and these become segregated while the molten magma is cooling and solidifying into the igneous rock; (2) the metals are gathered from the molten magma by highly heated vapors present in it, and expelled in gaseous form into the surrounding rock, or into the cooled upper portion of the magma itself; (3) the particles of metal are gathered out of the magma by heated waters, and carried in solution into the outer cooling portion of

the magma or into the surrounding rocks, where they are deposited as ore bodies. This third process is by far the most important, and it is now a well-established theory that the greater number of ore deposits have been formed by means of such heated waters. That the latter are competent to dissolve and transport metals is shown by the following facts: (1) warm water is known to be widely distributed through the rocks of the earth's crust, and much of it is in slow circulation—many deep mines, for instance, have hot waters flowing into them; (2) water, if it is heated or under pressure, and if it contains acids or alkalies, is a competent solvent for the minerals of ore deposits, analyses of mine waters and hot springs showing that they contain metallic compounds in solution.

It is well known that hot liquids, on cooling and loss of pressure, lose their power to hold substances in solution; hence the hot waters of the rocks deposit their dissolved mineral content as they cool in ascending through the colder rock, or when they come into contact with the walls of fissures. Furthermore these solutions, while in motion, are constantly undergoing chemical change due to their reactions upon the minerals through which they are passing, and accordingly they not only deposit substances but dissolve them as well. It is in this interchanging way that the metals and the less valuable minerals like quartz, calcite, etc., are deposited together.

Many ore deposits have been formed by rain water soaking through the ground and depositing them in enriched form at lower levels. Such are the lead and zinc deposits in the stratified rocks of the upper Mississippi Valley and the iron ores of the Lake Superior region.

To understand how this goes on, we must recall what was said in an earlier chapter about how soils are made and how pure rain water takes up acids out of the air and especially out of the soils. Water, even when pure, is a slight solvent of rock, and when acid and warm, is all the more so; hence all ground-waters have a more or less solvent action upon rocks and minerals, and deposit them along the lines of their travels. In this connection it must not be forgotten that geologic time is very long, and that an ore deposit may represent the accumulation of a lengthy period of time.

When ore bodies fill fissures or seams in the rock they form veins. They also occur, however, as lenses or beds, or fill the pores and coat the grains of sedimentary strata, as is commonly the case with iron-ores.

When a metallic mineral like iron is scattered in tiny particles it is valueless, but if the scattered particles are of gold they may be extremely profitable. A gold ore having only from two to five dollars worth in a ton of rock may be worth mining, and the same is true if there are 20 pounds of copper to the ton of rock. The Lake Superior iron ore has from 45 to 60 per cent of iron, but elsewhere iron ores of sedimentary origin having but 30 per cent of the metal are worked.

Chief among the metals in quantity of production, if not in pound-for-pound value, is iron. Thinly scattered iron is almost universal in rocks, but in commercial quantities and in a state nearly free of impure materials iron is not at all as common as coal. Native iron, i.e., iron in the pure state, is comparatively rare in the rocks, but the so-called magnetic and titanic iron ores are often common in igneous rocks where they crystallized out of

the melt as it cooled; the unexploited titanic ores in New York State are thought to amount to over a billion tons. The greatest iron reserves in the United States, however, are the hematites (oxides of iron), which occur in the very ancient sedimentary strata of the Lake Superior country, and in the younger marine beds in the Ap-

GOLD-QUARTZ VEIN

Plumbago mine, Alleghany, California. Note, at the left, where the vein has been quarried. Photograph by Ferguson, U. S. Geological Survey.

palachian Mountains from New York south to Alabama. Considerable amounts of iron ore also occur as carbonates in the sedimentary rocks, associated with coals.

Gold is usually found in the pure state as a native metal, but as a rule the metals are combinations of elements; for example, silver occurs combined with oxygen as an oxide, and with sulphur to form a sulphide or sulphate. Several ore minerals generally occur to-

gether, and nearly all of the commonly used minerals are mixed with useless ones, which are called gangue minerals, from an old mining term. For instance, the metal lead is chemically combined with sulphur in the ore-mineral galena, and the galena is usually enclosed in a gangue of quartz or limestone. These gangue minerals must be removed in order to get the metals in their purity, and this purifying of metals is the art of metallurgy.

Sometimes nature relieves man of the necessity of mining, crushing, and concentrating ores in order to obtain their minerals, by breaking up the rocks that contain them and moving the resulting loose material down into streams, where the water carries away the lighter rock particles, while the heavier minerals sink to the bottom and are held there in holes and crevices or between the pebbles and boulders. The few scattered grains of minerals in each ton of débris will thus be concentrated in the bottom gravels of the stream, giving rise to the so-called placer deposits. Free gold occurs more often in this way than any of the other metals, and it was the discovery of it in stream gravels that lured the forty-niners to California and brought to the Klondike miners and adventurers from all over the world.

Copper, probably second oldest among the world's known metals, has grown enormously important in recent years because of its use in the electrical industry. It occurs in many combinations, most important of which are the sulphides. The process of refining the ores to obtain the pure metal has been carried to a great degree of perfection in this country, so that not only do we produce two-thirds of the world's copper, but the bulk of that mined in South America, Mexico, and Canada comes

to us for smelting. Hence copper is one of our greatest sources of national wealth.

The Lake Superior copper region, worked in prehistoric times, was rediscovered in 1830, and has been a steady producer since 1847. Great fortunes have come from this part of the country, notably from the famous Calumet and Hecla mines, and its superiority as a copper producer was unquestioned until challenged by the Butte region of Montana in 1880. The mines at Butte had been worked since 1864, but first for gold and later for silver; beginning with 1872, however, the presence of copper was demonstrated, and with the erection of a reducing plant seven years later, Butte began to develop into the most important copper camp in the world. Next to swing into line were the great Arizona mines—Bisbee, Globe, Morenci, Jerome—which have now brought to that state the title of master copper producer, though by only a margin of 1.13 per cent over Montana.

The mineral materials of the earth's crust were put there by nature, taking in many instances millions of years to accumulate, and once taken out of the ground they are not replaceable. Unlike the forests and crops, minerals, metals, and rocks do not grow. In his use of this natural wealth, therefore, man should not be wasteful, but should keep in mind the needs of the coming generations of humanity.

POND FILLING WITH VEGETATION, PEAT FORMING BELOW

CHAPTER IX

SWAMPS AS FUEL MAKERS

IN humid climates of low lands where there is little or no drainage, water will gather during the wetter seasons or throughout the year. Such areas may be small or very large; the Dismal Swamp of Virginia and South Carolina, before it began to be drained, was 40 miles long and 25 wide, containing Lake Drummond, which was 6 miles across. Swamps or bogs, then, are spongy low grounds saturated with bog water, or covered some feet deep in places with standing fresh waters. Naturally such places will abound in vegetation, but nearly all of it is specialized kinds of grasses, trees, and other plants adapted to these peculiar environmental conditions, such as mosses, water-weeds, rushes, pond lilies, and cypress trees. All such undrained places are destined to fill up somewhat with muds, but mostly with fragmentary plants, and then to pass into moist grassland or forests.

THE LUXURIANCE OF A PENNSYLVANIAN COAL SWAMP

Pictured by the paleobotanist Potonié for the Deutsches Museum, Munich, by whose permission it is here reproduced.

Lakes in humid climates also go over into swamps with an abundance of plants. While the lake exists, the soil of the adjacent lands is being washed into it, and eventually it will be filled, first with rock sediments, then with muds and plants, and finally with plant accumulations. As the waters become shallow, the water-loving plants of the margins spread more and more inward, and at last completely cover the surface of the water with bogs that hasten the filling process through accumulations of plant fragments held in a black carbonaceous mud, which together go to make peat. In northern countries the bogs tend to fill up mainly with bog-moss or sphagnum, which is much used because of its antiseptic qualities.

Swamps are most common along the lower courses of

rivers where they meander through the low lands. A large portion of the river plain of the Mississippi, for example, estimated to cover an area of 30,000 square miles, consists of extensive swamps. Marine marshes, on the other hand, occur along the seashore and especially where the lands are very low, large deltas being replete with them. Here in the shallow brackish water there live submerged land plants like eel grass, which hold the muds brought to them. Eventually, when the sea-water is excluded through mud and plant filling, a fresh-water swamp will take its place, with an entirely different set of plants. It is the marginal plants—in Florida the thickets of man-

A PRESENT-DAY COAL SWAMP

Portion of the Dismal Swamp, showing the same luxuriance of vegetation as in the preceding figure, but of very different kinds. Peat is forming in this low wet area. Photograph by the U. S. Geological Survey.

groves—that keep the muds and saline waters from getting into the centers of bogs and swamps where the pure peats accumulate.

Peat, then, is nothing other than an accumulation of fragmented and rotted land plants mixed with more or less of mineral impurities, some of which are of the plants themselves but most of which come from the rock-mud washed into the bogs. When peat is pure, it is a brown to black carbonaceous accumulation of decayed plant material. Charcoal may become mixed with the peat when the trees of a bog are set on fire by lightning or otherwise, but charcoal is also a plant fuel.

Cellulose ($C_6H_{10}O_5$), the chief plant material, is oxidized rapidly when burned in the air, but under water the oxidation goes on very slowly through the action of bacteria, and hence it is only partially decomposed or consumed. Accordingly in the process of accumulation some hydrogen is lost as water (H_2O), some carbon as carbon dioxide (CO_2), and more of both vanishes as marsh gas (CH_4). The resulting decayed plant material, the peat, is therefore relatively much richer in carbon and poorer in hydrogen and oxygen than the original cellulose. Where there is little or no circulation of the water in the swamps and bogs, the plant acids accumulate, and kill off nearly all of the bacteria, thus arresting the process of decay and preserving the peat. Cedar logs, animals, and human bodies are also preserved in such antiseptic swamps, and their waters are sought after for ships about to start on long voyages, since they remain free of contamination and diseases.

Peats made by different sets of plants have been accumulating since early in geologic time, and it is from

these that our great stores of coal have come, ordinary coal being a greatly compacted stratified mass of peat. The plants can often be seen in the coal, and especially the woody fibers. When coal is subjected in very thin slices to the microscope, the recognizable parts are seen to be most often coverings of spores (reproductive bodies analogous to seeds), and charcoal remainders of burnt wood. Some coals appear to be structureless, a sort of solidified jelly breaking down readily into cubical blocks.

The several varieties of coal depend upon the amount of muds mixed with the plants when the peat bed was forming, upon the degree of subsequent carbonization, and upon the proportion of fixed (carbon) and volatile matter (oil and gas). When heated, "bituminous" coals soften or even fuse; but it is a mistake to think there is bitumen present, since these coals consist largely of carbon with some oxygen and hydrogen present, and are therefore better spoken of as humic coals (from humus or vegetable mold). The "soft" coals retain much oil and gas, sometimes from 30 to 50 per cent, and hence they fuse and cake when burning, making the cokes. Anthracite, on the other hand, has from 90 to 95 per cent of fixed carbon. Lignites have a woody or clay-like appearance and, when green, have as much as 40 per cent of water; their heating value is therefore low, but they are the common coals of Mesozoic and Cenozoic times.

It is well known that volatile matter is constantly escaping from coal in mine tunnels, and that the gases thus released may become ignited, causing the disastrous mine explosions. When the coals are unexposed to the air, the gases cannot escape because of the impervious rocks. If the volatile matters had been constantly escaping dur-

ing geologic time, we should expect all of the oldest coals to be anthracite, but this is far from being true. Where anthracites occur, it is because the earth has been greatly squeezed in mountain making, cracking the rocks enclosing the coals and making them more or less porous (schistose), and thus permitting the volatile matters to escape during the long geologic ages. It is in anthracites, therefore, that we see the greatest concentration of carbon with the least volatile matter.

It has been noted that plant stems in coal are now from one-seventeenth to one twenty-fourth of their original thickness, and this gives some idea how much is lost in passing from green plants to coal. If compressed peat accumulated at the rate of one foot per century and the same thickness of coal in three centuries, it probably took about two thousand years for sufficient plant material to accumulate to make the seven feet of good coal in the Pittsburgh bed. Of course a vastly longer time elapsed before this accumulated material was changed into hard coal by the processes indicated above.

As a rule, coal beds occur between mudstones and sandstones that are of fresh-water origin. The roofing mudstones or shales are often replete with fine specimens of ferns and other land plants, while beneath the coals there are frequently old soils filled with the roots of plants. These old soils have usually been changed by the percolating acid waters of the swamps into fire-clays, the water taking away most of the iron, soda, potash, and lime, and leaving behind the less fusible aluminous clay and sandy matter.

Coal beds vary in thickness from a mere film up to about 80 feet. A workable bed must be at least 2 feet

thick, and it is very seldom that they are thicker than 8 to 10 feet. The Mammoth anthracite bed of Pennsylvania, however, has a maximum thickness of about 45 feet.

The coal fields of the United States east of the Rocky Mountains, probably the largest in the world, are estimated at about 250,000 square miles, but our total coal area covers 495,000 square miles, estimated to aggregate 3,150,000,000 tons. China comes next in amount of coal area. Russia has 27,000 square miles, Great Britain 9000, Germany 3600, France 1800. At the present rate of consumption the coal of this country will last us 1500 years, and no other nation has so much sunshine and energy locked up for the future.

In the accumulation of peat we have seen how some volatile matter is constantly escaping, and again, when coal is exposed in mining or is burned, how oils and gases are liberated. In many places, however, oil or petroleum and natural gas are flowing out of the earth's crust, showing that these materials are widely disseminated in the rocks. Let us see how they got there.

Petroleum and natural gas are mixtures of carbon and hydrogen: in short, hydrocarbons. They are the gaseous decomposition residues of plants and animals that lived in bygone times, and mainly in the seas. Forming at the time when the marine strata originate, these hydrocarbons are stored away in solid form in muddy rocks and mainly in black shales laid down in stagnant waters. From these mother oil strata they are subsequently freed as liquids or gases by the circulating ground waters that are under great pressures, and by these waters are lodged in porous or cavernous formations, mainly sandstones. The

rocks in which the hydrocarbons are thus stored are then tapped by wells drilled into them at depths of anywhere down to 5000 feet or more.

Petroleum is rapidly coming to be the preferred fuel, and has become the concern of many nations through its use on land and sea and in the air. In the United States the oil industry began in Pennsylvania in 1859 with a production of 2000 barrels. In 1925 the yield had risen to the astonishing figure of 750,000,000 barrels and the annual yield of natural gas and oil is now worth not far from one billion dollars.

DOME-SHAPED HILL OF GLACIAL DRIFT, OR DRUMLIN

CHAPTER X

GLACIERS AND LAND SCULPTURING

The action of flowing ice, whether in the form of river-like glaciers or broad mantling folds, is but little understood as compared with that of other sculpturing agents. Rivers work openly where people dwell, and so do the rains, and the sea thundering on all the shores of the world; and the universal ocean of air, though unseen, speaks aloud in a thousand voices and explains its modes of working and its power. But glaciers, back in their cold solitudes, work apart from men, exerting their tremendous energies in silence and darkness. Coming in vapor from the sea, flying invisible on the wind, descending in snow, changing to ice, white, spirit-like, they brood outspread over the predestined landscapes, working on unwearied through unmeasured ages, until in the fullness of time the mountains and valleys are brought forth, channels furrowed for the rivers, basins made for meadows and lakes, and soil beds spread for the forests and fields that man and beast may be fed. Then vanishing like clouds, they melt into streams and go singing back home to the sea.—John Muir

IN previous chapters we have been following the work done by water, either as vapor or as liquid, and now we are to see what it does as a solid. It is well known that water increases in volume as it freezes, and consequently when the cracks in rocks are filled with water and this becomes solid, they are split more and more. Snow is crystallized water, and glaciers are thick masses of moving ice compacted from snow.

With the exception of Australia, all the present continents have areas of perpetual snow, though those of

ILLECILLEWAIT GLACIER

The main glacier, at the right, lies on the slope of Mt. Sir Donald, in the Selkirk Range of Canada. Note also the small tributary glacier toward the left. Photograph by Notman.

Africa are rather limited. In the tropics such can occur only in the highest mountains, in temperate regions they come down to much lower levels, while in arctic lands the snowfields approach the sea. Therefore in passing from the equator to the poles there is a descending altitude at which snow lies all the year, and this imagined level is called the snow-line. At the equator it lies from 15,000 to 18,000 feet high, in Yellowstone Park about 10,000 to 11,000, in southern Alaska about 5000, in southern Greenland about 2000, and in northern Greenland below 1000 feet.

The high mountains are the gathering fields of perpetual snow. Here in catchment basins it accumulates to depths of hundreds of feet, becoming more and more compacted into solid ice as the weight above increases. With the growing thickness, the ice can no longer hold its place on the slope, and the actual glacier movement begins, the mass moving slowly down the valley that forms the outlet of the catchment basin. These so-called alpine or valley glaciers are to-day the most common type. If the valley glacier is in arctic lands, it may terminate in the sea and give rise to floating icebergs; if in warmer regions, its front gradually melts away as it reaches lower levels and the glacier becomes a rapid river. At their lower terminals, glaciers do not, however, melt steadily back at an equal rate over long periods, but grow and advance or diminish and retreat in response to varying climatic conditions. It is not yet definitely known, in fact, that the present glaciers of the Alps and of North America are in general retreating and melting away wholly, but this is believed to be the case.

The icebergs of the seas and oceans are broken-off

fragments of glaciers, composed of pure water, and the tabular ones have seven feet of ice beneath the water for every foot projecting above it. Some of these great bergs have been seen to project 200 feet or more above the sea; hence such masses are more than 1500 feet thick. The winds and sea currents drift them about until, striking bottom, they "calve" and are broken into smaller masses. Gradually they drift into warmer waters and, taking on fantastic shapes, are finally melted away in the north and south temperate regions. These icebergs often carry within themselves much rock débris and this is distributed far and wide over the ocean bottoms as they melt.

The best-known glaciers are those of the Alps, some two thousand in number, the great majority of them less than a mile long, but some ranging from 3 to 5 miles and the Aletsch to 10 miles. Still greater ones are known in the Caucasus, the Himalayas, the southern Andes, and in Alaska where they reach lengths of 50 miles and breadths of 3 to 5 miles. The Alpine glaciers move from 300 to 1000 feet in a year, but some of the larger ones in Alaska advance from 4 to 40 feet a day, Muir Glacier having a record of 2000 feet per annum. In Greenland, where the valleys entering the sea are gorged with ice and the glaciers have great heads of pushing highland ice behind them, the movement may reach 60 or 70 feet a day. The glaciers do not move as a whole, but their motion is differential, faster in the center than at the sides, and at the top than at the bottom, after the fashion of a thick fluid like pitch or asphalt.

Moving glaciers, like rivers, do their geological work through erosion, transportation, and deposition, but the

manner of this work and the resulting deposits are unlike those of rivers and winds. High in the mountains, where the snows gather, the thawing, freezing, and sliding of snow are very active during the warmer seasons. With the added weight of the accumulating and sliding snow, the rocks are all the more easily fractured and broken out, and this rapid quarrying results in the huge crescentic basins called cirques or amphitheaters, in which the glaciers have their origin. In addition to this original load of abrasives, the glacier constantly gets more tumbled-down rock from the weathering mountain sides. The largest pieces sink into the ice, while at the bottom the ice freezes into the cracks and cavities of the rock floor and around its projections as well. Then, as it moves, the glacier plucks away these latter masses of rock and carries them forward with it.

All of the rock that gets to the bottom of the glacier, of whatever size and however obtained, is used by it to corrade, groove, scratch, channel, and polish the valley floor and sides until the ice melts away under the warmer atmosphere at lower altitudes. In this way glaciers deepen and widen the valleys down which they move into U-shaped ones, contrasting with the V-shaped valleys made by rivers within the mountains which have in addition lateral hilly spurs coming in on alternate sides of the rivers. An example of a river valley thus changed and deepened several hundred feet, while its tributary valleys remained at a higher level and must now perforce discharge their streams into the main valley over high waterfalls, is to be found in the picturesque Yosemite Valley of California.

Characteristic of regions that have suffered glaciation

are the polished pavements marking the path of the former glaciers. Those of the Sierra Nevada, Muir says, "are simply flat or gently undulating areas of solid resisting granite, the unchanged surface over which the ancient glaciers flowed. They are found in the most perfect condition at an elevation of from eight to nine thousand feet above sea level. Some are miles in extent, only slightly blurred or scarred by spots that have at last yielded to the weather; while the best preserved portions are brilliantly polished, and reflect the sunbeams as calm water or glass, shining as if rubbed and burnished every day, notwithstanding they have been exposed to plashing, corroding rains, dew, frost, and melting sloppy snows for thousands of years."

The surfaces of glaciers are not smooth but more or less uneven because of unequal melting, and in addition they are variously split open by crevasses or fissures that may be 20 feet across and 100 feet deep. Into these fissures rushes the melting water, to emerge again at the termination of the glacier as a swift-moving river, so heavily charged with unweathered rock particles as to have a characteristic milky appearance.

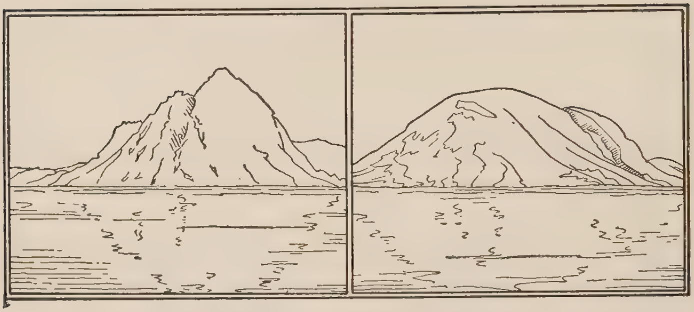
Where the melting glaciers terminate on the land, the transported rock material is piled up in moraines, confused masses of unassorted and highly variable rocks and earth, usually a few tens of feet high but sometimes hundreds and even a thousand feet across, the size depending mostly upon how long the ice front remains in the same place. The harder boulders are commonly scratched and polished, and some have had flat surfaces or facets ground on them; other pieces are as angular as when broken out of the country rock. These

unstratified and heterogeneous morainic accumulations, known as glacial tills or drift, are as characteristic of glaciers as stratified and assorted sands, muds, and limestones are of rivers, lakes and seas.

In contrast to the more common valley glaciers, Greenland and Antarctica have ice-caps or continental glaciers

SNOUT OF THE SASKATCHEWAN GLACIER, CANADIAN ROCKIES
Note also the lateral moraines on either side. Photograph by Harmon.

of enormous extent and thickness, those in the former country covering over 700,000 square miles to a depth that may be several thousand feet. These also are in motion, but apparently very slowly excepting along the margins of the continents where they descend rapidly down the valleys into the sea. The ice-cap of Antarctica covers several million square miles and ascends to 9000



EFFECTS OF GLACIATION

On the right, a hill that has been overridden by an ice-sheet; on the left, one that has been subjected to no such ice action. After Chamberlin and Salisbury.

feet above sea-level. Thinning toward the sea, it floats upon vast stretches of it as the "Great Ice Barrier," which gives rise to the huge icebergs so common in the Antarctic Ocean.

Naturally these vast continental ice-caps do vastly more destructive and constructive work than the valley glaciers. They move radially outward from their gathering centers, sometimes more than 1500 miles across the country, scouring and plucking it, and scooping out many shallow basins as they go. When the ice-caps have melted away, the land is seen to be everywhere scratched and polished, with all of the harder projections evenly rounded, and glacial lakes occupying the depressions. The ground is strewn with strange rocks, the erratics or glacial boulders, angular or well rounded, some of them as large as houses. The glaciation leaves still other records in long winding ridges of sand and rock (eskers) piled up by rivers running underneath the glaciers, or in hummocks, knobs, or low rounded hills of drift elongated

GLACIAL LANDSCAPES IN NEW YORK STATE

Above, ridges, or kames, near Mendon; below, a moraine near Danville. Photographs by Fairchild.

in the direction of ice movement and known as drumlins. Elsewhere there are sheets of till and sands spread out by the waters of the glaciers, and banded clays, the deposits of temporary lakes formed in front of the retreating ice. This material ranges in depth from a few feet up to 500 feet. Much of the previous drainage is altered, the old river valleys being choked in places with

AN ESKER

A long winding ridge of glacial sands and gravel, probably deposited by a stream flowing under an ice-sheet. Such ridges are usually miles long. After Pirsson.

rock débris, so that the streams take to making new courses; some of the rivers are also dammed back by the débris and changed temporarily into lakes. All of these results of glaciation, as they are to be seen in this country, will be discussed more in detail in a later chapter on the Great Ice Age.

Glaciers in the mountains erode and widen their valleys, and this process is continued by the thick continental ones even beneath sea-level. In this way have been made in part the very beautiful fiords of Norway, some of which are 100 miles in length and from 1000 to 4000 feet deep, with precipitous walls that rise from

1000 to 3000 feet above sea-level. These deeply flooded valleys are, however, not altogether due to the work of eroding glaciers, but in part owe their depth to subsidence of the land after the fiords were made.

As all of these "seas of ice" came from the oceans, the present strand-line in the tropical and warm temperate regions at the times of greatest glaciation was lowered probably not less than 200 feet and not more than 420 feet. On the melting of these continental glaciers, the sea has risen gradually to its present level.

Photograph by Campbell

DESERT ROCK CARVING, ARIZONA

CHAPTER XI

DESERTS, DUST, AND WANDERING SANDS

Deserts are the lands of geographic paradoxes: storms without rain; threatening clouds that leave no moisture; springs without brooks; streams that gradually vanish; nameless lakes with no fixed shores, which evaporate away within a few years or change their places in the course of time; lakes with no outlets, but with a salt content so high that the coldest of winters do not freeze them over; waterless valleys and dry deltas; depressions that lie beneath the level of the sea . . . labyrinthine valleys that descend the hills, only to ascend them again; great cauldron-like pits out of which no valley leads; human beings that know no home and shift their habitations as restlessly as the yellow sand hills that the wind drives.—Johannes Walther

THE arid regions are indeed the strange places of the earth. "The chief glory of the desert is its blaze of omnipresent light." Here the air is dry and thin, the scenery is colorful, strange, and fantastic in sculpture, the days are burning hot and windy, while the nights may be refreshingly cool and calm; hardly anywhere is

water visible, and what there is, is likely to be salty or bitter. Hence plants are either wholly absent or scattering, and all are highly modified and adapted to the abnormal life conditions. Nevertheless in the midst of all this aridity there are occasional oases with an abundance of water and hence of life.

In humid regions the dominant color of the landscape is the green of vegetation, but the desert makes up for its lack in this respect by the colors that come from the rocks themselves. These are browns, delicate golden yellows to brilliant orange yellows, bright leather yellows to dark coffee browns, and the deepest of umbers. Most vivid of all are the shades of red which appear shortly after sunrise and just before sunset, when the shadows also are longest and bluest.

One-fifth of the present lands are arid, and as erosion and sedimentary accumulation are rapid under these conditions, they are important areas geologically. Where the average annual rainfall is less than 20 inches, the climate is semiarid to arid. In the semiarid or bush-deserts there are annually one or two seasons of rain, and in Arizona there may be from 6 to 26 inches (in the high mountains) of rain in a year. In the flat arid deserts rain does not come every year, and there may be none in four (West Australia) to even ten years (Egypt). The rains may be light, but often they are very heavy, and not infrequently there are devastating cloudbursts. In the deserts of West Australia, where it rains only at long intervals, there may fall in a day or two from 27 to 35 inches of water; rivers may then swell quickly to 100 feet of depth and a few months later have vanished. Here the air is very dry and the evaporation amounts to 142

inches in a year. In 1892 at Cairo it rained but one-quarter of an inch, and in 1904 nearly 3 inches fell, half of this in a single day.

In the desert regions it rains more often near the margins, adjacent to the humid climates, and in the high mountains whose cool touch takes the moisture out of the atmosphere and sends it down as rain or snow. From the mountains the run-off flows into the deserts to form their evanescent lakes, or sinks through the loose rocks of the upper slopes and the plains, but most of it is rapidly evaporated away by the dry air. The latter even affects the ground-waters, acting like a suction pump in pulling them up through the smallest of crevices to the surface, where they evaporate, leaving behind the salts they have taken into solution while percolating through the ground.

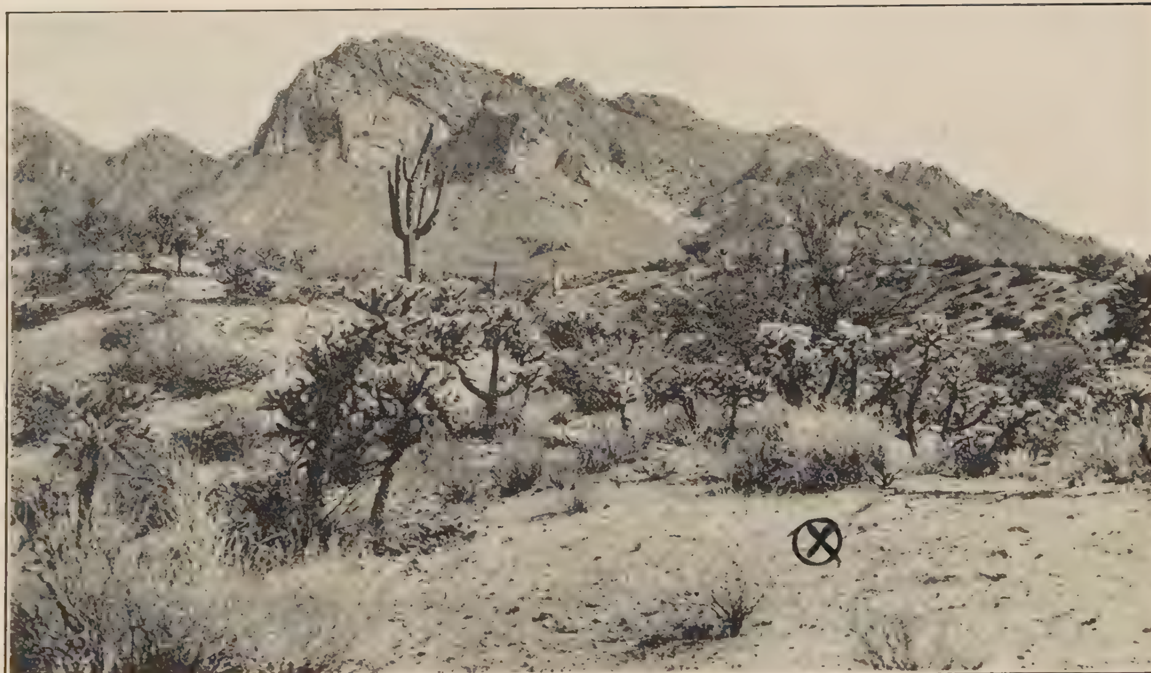
Since evaporation in the deserts naturally exceeds rainfall, the rivers are short-lived, and none of those originating there flow out as living streams. Great perennial rivers, like the Nile, or the Colorado, may flow through deserts, but they are fed from sources outside of the arid regions, either in humid climates or in the high mountains.

Desert lakes are also rarely permanent. After the extraordinarily heavy rainfalls, the run-off or sheet-floods will gather in the hollows of the plains where they make lakes, usually but a few feet in depth, which are known as playa lakes because the deposits spread out thinly and widely by their muddy waters form monotonous plains called playas. The sheet-floods also take up all the salts that have effloresced on the surface, and in the central part of the playas these are deposited through

AN EROSION REMNANT

Venus Needle, Todilto Park, New Mexico, a high column carved out of varicolored sandstone by the weathering forces of an arid region. After H. E. Gregory.

Tullie



X marks the spot

ROCK WEAR IN THE DESERT

Ancient rocks, rapidly disintegrating to make the present floor of the desert, and the scanty soil for its cacti. Santa Catalina Mountains, Arizona.

the final evaporation of the water. There are, however, also permanent lakes without outlets, among them Great Salt Lake in Utah, Pyramid Lake in Nevada, Mono Lake in California, the Dead Sea in Palestine, etc.

Because the air has so little moisture in arid regions, the sunlight passes through it in greater volume, and, striking the rocks, is converted into heat. As there is no moisture to hold this heat, it radiates away very quickly during the night; hence the days are hot and the nights cool to cold. The rocks in a single day may be subjected to a temperature change as great as 80° F., and a rain may quickly cool them as much as 60° F. Such great changes rapidly fracture and fragment the rocks; in the Sahara, the abrupt change from night to day is occasionally accompanied by "cries" from the rocks, as when the Colossus of Memnon "salutes the dawn" at the first touch of the sun. The dry air also readily lifts, flakes, and peels the outer surfaces of the rocks, a process which is known as exfoliation. Exfoliation is the most important factor in deserts, and with the aid of the winds is responsible for most of their sculpturing.

One must go into the mountains or to the dry valleys and cliffs of the table-lands (mesas) to see the highly destructive work of desert climates. The well-cemented sandstones weather much the most slowly, and even the limestones are fractured and dissolved away. The hardest of granites are broken into boulders, gravel, and sand, and, in the main, the sands of deserts come from this source. Everywhere the rocks stand naked, endlessly fissured, split, or etched according to their massive or bedded character, their solubility or their friability. Some of the rocks are ready to fall, and in the past,

piece by piece, the high crags have fallen into trains of rock descending the mountain grades toward the gulches. Here they lie slowly creeping and breaking into still smaller pieces, while the winds blow away the dust made through exfoliation, and the lighter rains wash to lower levels the gravels and sands. It is a wilderness of jagged and angular rocks of all sizes. When a cloud-burst comes, the steep gulches are a-rumble with the moving, grinding mass; everything loose is being tossed about by the water rushing down the grade, and large and small rocks, gravel, sand, and mud move down the gulch and over the long slopes toward the plains, where they come to rest. Such long dry slopes (bajadas), built up of unassorted rocks, mud, and sand, are often miles in length, ever extending and raising the basin plains to higher levels. Some of the valleys between the mountains are now filled thousands of feet deep, and eventually the mountains will be buried beneath their own wastage.

With the rocks thus broken up and pulverized into fine particles, the next point to consider is their transportation, and here is where the desert differs from humid regions in that much of this work is done by the wind with the help of occasional showers, instead of largely by water. Where there is an abundant rainfall that is fairly equally distributed throughout the year, as is the rule in moist climates, there occurs a prolific growth of plants whose roots hold the soil from being washed away. In deserts, however, it is quite otherwise, for here the plants are usually widely spaced, and the soil, freed from their restraining influence, is at the mercy of the wind and rain. Strong winds are characteristic of most deserts.

AN APPROACHING SANDSTORM

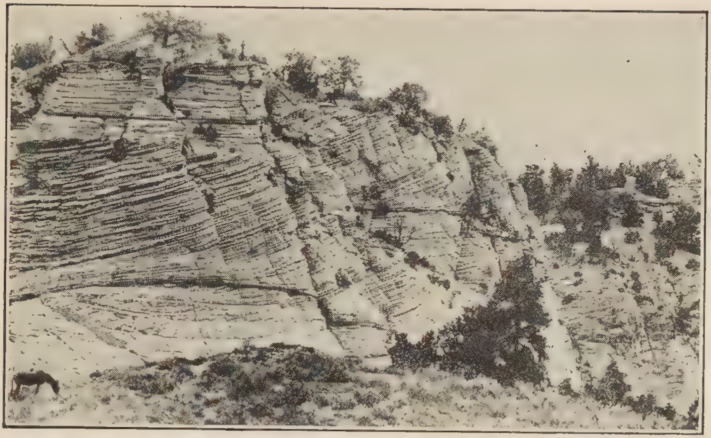
Storms such as these blow out of the deserts hundreds of thousands of tons of dust, often spreading it over regions many hundreds of miles distant.

The heated air, rising rapidly, leaves behind a vacuum into which rushes the colder air from the outer regions. Some days the wind thus set in motion maintains a rate of 50 miles an hour until sunset, when the heat ceases to radiate from the rocks. During many of the sunny days, in fact, the wind in most deserts moves so swiftly that it lifts and carries through the air not only the dust and sand but pebbles as large as peas, and during the tempests stones as large as the hand will be moved over the ground. This work done by the wind is called deflation. The dry desert sandstorms sand-blast all the rocks violently and the dust polishes their surfaces. In this way also telegraph poles are cut through near the ground

by flying sand, and even the hanging wires are worn to half their original thickness in ten or eleven years. Accordingly where the winds are strong the desert floor is a mass of loose and more or less angular rocks.

A single great storm in 1901 blew out of the Sahara 500,000 tons of red dust, which fell over central Germany as far north as the Baltic. The "blood rains" of Italy are due to this same wind-borne red dust, washed down by the rains. A great storm moving from the arid Southwest of the United States has been known to raise and carry into the region of the Great Lakes a million tons of dust. In this way there has been deposited in the central part of the Mississippi basin, and especially in Iowa, Kansas, and Nebraska, during the recent geologic past (Pleistocene), a peculiar structureless, vertically cleaving, yellowish earth in places reaching a depth of 20 feet. This so-called loess is common in areas adjacent to deserts, where it is held by the grass, the roots of which give rise to its vertical cleavage. North Central China is thus deeply and widely covered, especially in the valleys, with the wind-blown loess derived from the adjacent arid areas. How much dust is blown annually into the oceans from all the lands is unknown, but it must be considerable.

In the deserts themselves, and especially in the drier ones, quartz sand is blown along the ground and piled into characteristic sand hills as high as 300 feet; these are known as dunes. Many of them take on a crescentic form, and all have their surfaces marked by wind ripples. In the deserts the dry sands are constantly moving back and forth with the changing winds, but where the winds blow in one direction for the greater part of the

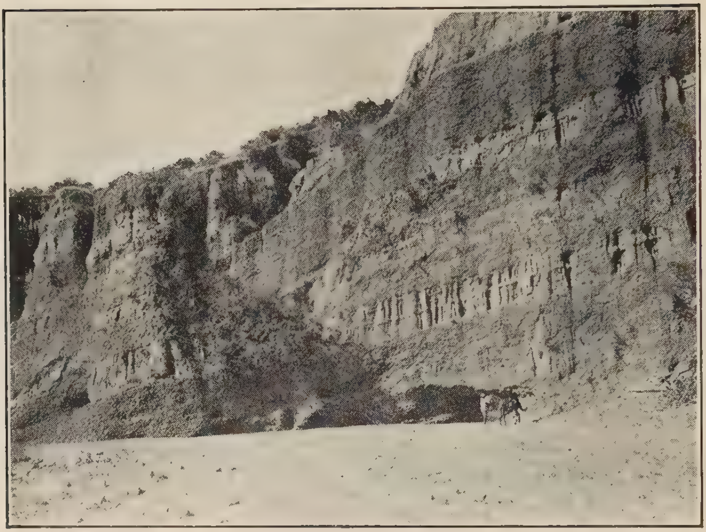


DESERT CROSS-BEDDING

Characteristic of dune sands blown together by the wind and later consolidated into rock. Walnut Canyon, Arizona. Photograph by the U. S. Geological Survey.

year the sands will travel out of the arid region into a moist one, or even into the seas and oceans. Farms, houses, and even cities have been buried in this way. Dunes also occur in wet climates along the sea or lake shores and where there are unconsolidated sands, the beach sands being washed clean by the waves, and, when dry, drifted inland by the strong winds. Marching sand dunes are, however, especially characteristic of the Asiatic and African deserts, and many such inhospitable areas are hundreds of miles across.

Marine strata can originate only below the level of the sea, but desert deposits of great depth and wide distribution are built up in arid regions without reference to altitude and distance from the oceans. As the thickness of a marine sedimentary series is conditioned by the



CONTINENTAL DEPOSITS, LAID DOWN UPON THE LAND

Siwalik beds of alternating bright-colored conglomerates and clays (vertically marked), thousands of feet thick, in the foothills of the Himalayas. Photograph by Barnum Brown.

original depth of the basin, or by its long-continued sinking while the deposits are accumulating on its bottom, that of a desert area is conditioned by the speed with which the highlands are broken down, and the depth of the structural valleys in which they accumulate, plus the work of the wind. The latter, as we have seen, can easily move vast amounts of dust and sand far into the heart of a continent, irrespective of grade or gravity. It is therefore apparent that very thick deposits of sandstones devoid of marine fossils can be made only in deserts. If such areas of accumulation are also sinking ones, then in them may gather surprising depths of rock

detritus and chemical deposits. It must not be forgotten, however, that flowing rivers and standing waters also play a rôle in arid regions, and that the oceans have in the past easily transgressed them and flooded wide areas.

One of the marked characteristics of deserts is their accumulations of chemical deposits consisting of various kinds of salts. These occur crystallized in the clays and sands, or are deposited in beds as gypsum, table salt, borax, thin limestones or dolomites, etc. The dry atmosphere evaporates the rising ground-water, leaving behind a whitened ground, and when the earth is completely dried these efflorescences are blown away with the dry dust. When the rain comes, the finer muds and these salts are gathered into the shallow lakes. Here the muds are quickly thrown down near the shores because of the saline waters, while farther out in the shrinking lake the purer salts accumulate. This accounts for the well-known salt and alkaline deposits of arid regions, with beds of gypsum, chlorides, etc. Such places are, however, more likely to have alternations of gypsum or table salt with clay bands or zones of sands which have been blown or washed into the lakes. As Walther says, the deserts are "nature's chemical laboratories," tending to separate out various kinds of minerals and salts; whereas the oceans, on the other hand, mix together all the salts received from the lands and keep them in solution because of the great amount of water constantly present. But when epeiric seas extend into the deserts, they also leave behind saline deposits and usually in far more extensive and thick accumulations than do the saline lakes or playas of the deserts.

A great part of the desert's inhospitality is due to the

presence of these salts. Intense heat man has learned to endure if he has a supply of pure water. The desert, however, forces him to travel over blistering sands, under a pitiless sun, and denies him the boon of cool pure water, except in the rare oases. Water there is, in infrequent places, but so saturated with salts that the wayfarer who drinks it is in worse case than before. It is not surprising, therefore, that our own southwestern desert has its Death Valley, or that the word oasis has come to be symbolic of rest and refreshment.

Saline lakes occur at any elevation up to 16,000 feet above sea-level (Tibet) or even down to 1260 feet below it, as in the Dead Sea of the Jordan Valley. When such desert areas are in sinking regions, great accumulations of various salts, both impure and pure, may take place. As specialized plants are common about such water bodies, there may even be formed paper-thin carbonaceous layers between the salts, and when perennial streams flow into salt lakes, fishes, and even birds and mammals, will be entombed in the clay beds. The dry air of summers and the freezing temperature of winters also help to precipitate the salts, and when there is an alternation of seasons the salts will be distinctly layered or banded.

Great Salt Lake now has an area of about 2000 square miles and an average depth of 20 feet. It is about seven times as saline as the oceans, and a human being floats in it almost like cork in fresh water. In this lake there is of common salt (sodium chloride) about 400,000,000 tons, and of gypsum (sodium sulphate) about 30,000,000 tons. Calcium carbonate is deposited in granular form on the bottom of the lake. Great Salt Lake is the shrunken remainder of Lake Bonneville, which during

the Great Ice Age was ten times as great as the present remnant, and the former shore lines may be seen in terraces lying as high as 1000 feet above the lake of to-day.

We have seen that the ground-waters rising to the surface bring with them in solution various salts, and as the water evaporates, these salts are deposited all the way through the ground. It is in this way that many of the granular desert accumulations are cemented into porous rock, much of it looking like an earthy or spongy limestone with interbedded layers of stalagmite. Such deposits are common in the deserts of Arizona and Mexico, where they are known as caliche. Furthermore, hard-water springs pouring over the ground in deserts often leave behind, as they evaporate, clouded onyx marble, a calcium carbonate deposit.

The desert areas of the geologic past were not always in the same regions where we find them to-day, as revealed by the record of their characteristically red rocks with great scarcity of fossils and with accompanying beds of gypsum and salt. The oldest desert so far found in America dates back to a time early in the third era of geologic history (Silurian) and, curiously, it was situated in New York and Ontario, where it left behind a great store of salt and gypsum. The next geologic period (Devonian) bears evidence of aridity in the widespread red strata of New York and Pennsylvania, Quebec, and Scotland, and again at the end of the era, in the Permian period, there were great salt-depositing sea-basins in Kansas and Oklahoma and especially in Texas and New Mexico, where 50,000 billion tons of salt are stored deep beneath the present land surface. This Permian aridity, moreover, as we shall see later, was a leading factor in

the evolutionary advance of land life, changing the ancient forests into the modern ones, and the amphibians into reptiles, birds, and mammals.

Other ancient desert deposits are the red conglomerates, sandstones, and mudstones of the Connecticut Valley, which appear to be over 10,000 feet thick. New Jersey has rocks of the same kind and age (Triassic), but here the thickness is thought to be twice as great. Similar records of Triassic deserts are to be seen especially well in Arizona, Utah, and Texas, and the arid regions of the Mesozoic and Cenozoic eras were all in the western part of North America, chiefly in the Great Basin and to the south in Mexico, where they also lie to-day.

The abundance and the variety of life in deserts are of course small when contrasted with those of humid climates, and the extreme arid regions like the Sahara have an even scantier flora and fauna than the bush deserts of our own Southwest. All of this life is, however, exceedingly interesting because of its high specialization to cope with the frightful desert conditions.

The perennial desert plants are highly modified to resist heat and drought, and to preserve moisture. Their roots are very long and abundant, ramifying in every direction to find what little moisture there is, and in many species much thickened to hold it; while all the cacti and the Spanish bayonets are replete with spongy tissue for the storage of water above ground. To ward off the drying effect of the air these plants have, not large and flat leaves, but small and narrow ones, and these are usually highly varnished to hold in the moisture; many, indeed, have no leaves at all or lose them shortly after the rainy season. On the other hand, spines and thorns

are everywhere as protection against browsing animals, and many of the desert plants are veritable "vegetable porcupines." In addition the leaves often have unpleasant odors and tastes—are sticky, astringent, cathartic, emetic, or poisonous. In the high mountains of desert areas the floras are of course very different and not unlike the pine forests of similar altitudes elsewhere; and in them dwell the mule, deer, wolves, coyotes, cats, and mountain lions.

The plant life of our American deserts, although scanty, is easily seen, but one may go hours or even a whole day without seeing any animals other than circling flies, darting lizards, horned toads, here and there a wren or other small bird, occasionally a hawk or soaring vulture, often a jackass or cottontail rabbit, seldom a desert antelope. But at night, and especially when the moon is shining, many other kinds of animals come out of hiding, and these lure out of the mountains the preying coyotes and wolves and cats.

All these creatures are more subdued in color, more alert, and thinner than their kindred elsewhere; "there is nothing fat in the land of sand and cactus. Animal life is lean and gaunt; if it sleeps at all it is with one eye open. . . . At every step," says John Van Dyke in his wonderful book, *The Desert,* "there is the suggestion of the fierce, the defiant, the defensive. Everything within its borders seems fighting to maintain itself against destroying forces. There is a war of elements and a struggle for existence going on here that for ferocity is unparalleled elsewhere in nature. . . . It is a show of teeth in bush and beast and reptile. At every turn one feels the presence of the barb and thorn, the jaw and

paw, the beak and talon, the sting and the poison thereof. . . . There is no living in concord or brotherhood here. Everything is at war with its neighbor, and the conflict is unceasing. Yet this conflict is not so obvious on the face of things. You hear no clash or crash or snarl. The desert is overwhelmingly silent."

CHAPTER XII

PLAINS AND PLATEAUS

HARRISBURG GAP, PA., CUT THROUGH AN OLD PLATEAU

THE great level reaches of country that stretch away for miles to the horizon, while not so impressive scenically as the more irregular mountain areas, take on a new significance when seen through the eyes of the geologist, since they represent the attainment of the ideal toward which all the weathering processes are directed. Under favorable climatic conditions they are the most livable portions of the earth, affording no obstacle to the expansion of cities, presenting no intricate problems for transportation engineers, and repaying in generous measure the labors of the husbandman. Where nature is sterner they may, on the other hand, be barren and desolate wastes like that of Labrador, given over to forest, Indian, and caribou, and diversified only by a myriad of lakes. Or we may find them lying high above the surrounding country as extensive table-lands, like the Colorado Plateau, level only in a broad sense but

to a closer view showing canyons cut far below the surface by rivers, and mountains raised high above it by volcanic action. Each of these level areas represents, however, a stage in the eternal struggle between the erosive forces that tend to smooth out the irregularities of relief and to produce a near-sea-level plain, and the more mysterious forces within the earth that periodically elevate portions of the lands into low or high plateaus.

We have seen how the weathering influences break up and dissolve the country rock, and how the rains carry away the fragmented detritus and the dissolved salts; also that erosion is especially rapid in the highlands, where the stream gradients are steeper. In this way valleys are made and widened, hills reduced in altitude, and even the mountains are transported into the shallow seas, filling them with rock deposits. All this tends to the making of plains. When these level tracts are again elevated, they become the plateaus of the geographers, and their streams at once begin to incise themselves, reaccentuating the relief.

In the lowlands erosion goes on far more slowly, and finally, when their surfaces stand but a few hundred feet above sea-level, the lowering process almost ceases. It is therefore a question whether a matured plain could ever be developed over an entire continent, since it would take an enormous length of time to reduce all of its mountains to near sea-level. To do this the land in respect to sea-level would have to remain stationary during an extraordinary length of time, and geologic history shows that land surfaces sooner or later are warped or reëlevated, starting the work of erosion all over again. The level of the sea therefore is that below which land

cannot be worn down by the agents of erosion. (The sea can and does cut into the land, making limited wave-cut terraces, but such will not be considered in this chapter.) Sea-level extended as an imaginary level under the land is known as the ultimate base-level, below which erosion cannot go. Base-level, then, is the imagined plane toward which the land constantly approaches, but which it can never reach.

Plains have gently rolling broad elevations that everywhere rise to the same general height, and between them are wide and very shallow depressions in which the evenly graded streams wander more or less sluggishly to the sea. These features exist irrespective of the hardness or softness and the structure of the bed rocks. There are in fully matured plains no waterfalls and no lakes other than the cut-off meanders of rivers, the oxbows. Shallow marshes exist along the river courses, and along the sea front occur more or less large and shallow salt-water sounds behind the long and narrow outer barrier beaches of wave-washed clean sand. The sounds themselves may even be nearly filled with land-wash, leaving an occasional pond of fresh water.

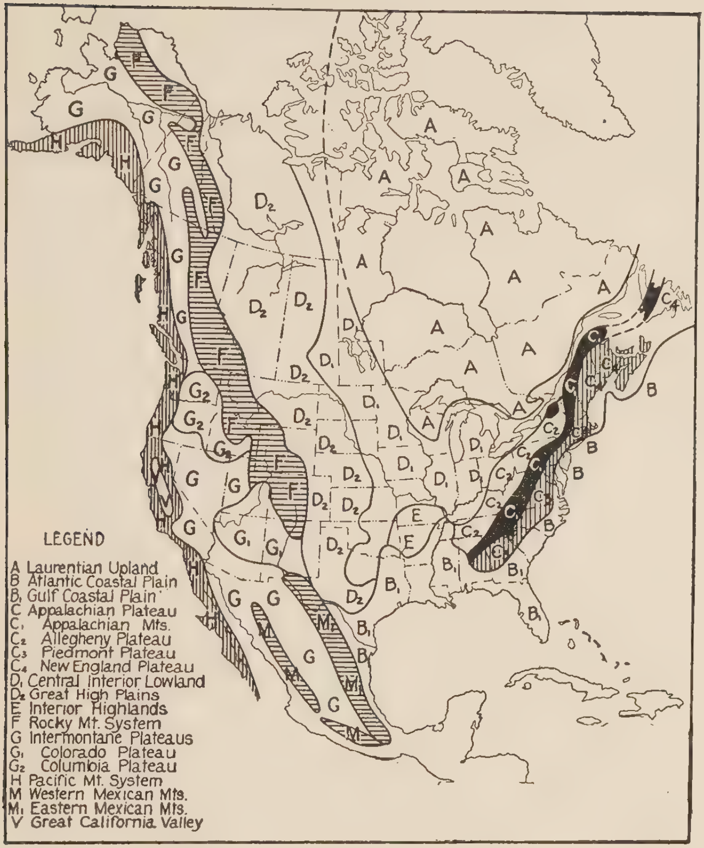
Plains are of different geographic extent and not all of the smaller ones have been made as described above. So far we have been considering mainly the destructive erosional work of weathering and rain, but rivers also do much constructive work with the products of erosion. Many streams, and especially the larger ones like the Mississippi, flow through lowlands in their later courses, and here during times of flood build up what are known as flood-plains. When the rivers of the lowlands are in flood, they overflow their low banks and their waters

spread far and wide across the adjacent flats, dropping their burden of muds and fine sands. This material is known as alluvium, and in the course of time the floods deposit layer upon layer of it and thus build up the alluvial plains over the older rocks. It is a curious fact that these alluvial plains are generally a little higher next to the river banks and from there slope gently on either side. The flood-plain of the Mississippi River, which was discussed somewhat in Chapter V, occupies 30,000 square miles, the larger portion of which is swampy and forest-covered.

Not only are the lands subject to change through erosion but, as stated above, they undergo as well changes in altitude with reference to sea-level; in other words, the lands from time to time are moved up and down, but in the main upward. Subsidence has occurred over and over again, and the oceans have repeatedly flowed widely, though at no one time deeply, over the depressed lands, yet the latter have as often been reëlevated into dry land.

The landscape of a plain or plateau presents a monotonous undulating surface which in the far distance appears to have a perfectly level skyline. Such a surface may, however, be diversified by an occasional hill projecting above the general level, which, on account of the more resistant nature of the rock composing it, or possibly because of its original greater size, has not been worn away like its neighbors. Such elevations above the general surface have been termed monadnocks, from Mount Monadnock in southern New Hampshire, which is a conspicuous landmark in the upland of central New England.

The most easterly of the North American plains is that



NORTH AMERICA'S MOUNTAIN AREAS, PLAINS, AND PLATEAUS

These are called physiographic divisions, physiography being the branch of geology that deals mainly with the relief features of the earth's surface. Chiefly after Fenneman.

along the Atlantic border. This, the Atlantic Coastal Plain, is an old marginal floor of the ocean, now raised out of the sea, and consists therefore of partially consolidated marine strata. Off the New England states it

is very narrow, or even submerged, but to the southwest of New York City it widens out rapidly, continuing as far south as Georgia, where, as the Gulf Coastal Plain, it swings to the west across southern Alabama, and thence very widely across the Mississippi lowlands. Well dissected and hilly in the interior, with local relief of from 200 to 400 feet, it gradually descends toward the coast, along which it exists as flat marshy surfaces that merge into the sea.

The Atlantic and Gulf coastal plains, being elevated sea-floors, are, like all our American plains, strictly speaking, plateaus. The distinction between the two is, however, sometimes difficult to draw, because some small plateaus, and even certain extensive ones, have been elevated but little and still retain their old surfaces. The younger plateaus still show most of their original flat surfaces between the more or less deeply entrenched rivers; the older ones have broad drainage slopes with widely spaced and flat areas which are the remnants of the ancient plain. Finally, plateaus develop again into plains at low levels.

To the west the Atlantic Coastal Plain is bounded by a more hilly and deeply dissected, also westerly ascending, upland known as the Piedmont Plateau. This is made up in the main of hard crystalline and highly altered rocks of very ancient origin, in contrast to the easily eroded younger beds of the Coastal Plain. Consequently the juncture between the two is marked by the "fall line," where the rivers plunge over the last hard rocks of the upland down to the softer ones of the coastal plain. Along this "fall line," both because of the water power that it generates and because it necessarily becomes the

head of navigation, lie most of the great cities of our eastern seaboard. (See figure at the end of the chapter.)

Most difficult of all our plateaus to understand, because its original character has been lost to so great an extent, is the Appalachian one. It seems strange to think of the Appalachian Mountains as a part of a plateau, but this becomes apparent if one studies the skyline, when the tops of the mountains are seen to lie at the same general level. This is especially marked on the opposite banks of the river courses, as, for instance, along the Potomac River and about Cumberland, Maryland. The Appalachians of to-day are in reality but the rumps or roots of a once majestic range that was made at the close of Paleozoic time and worn away to near sea-level during the succeeding eras. To the east of this medial area is the Piedmont Plateau which slopes eastward into the Coastal Plain; to the west, the wider and westerly sloping Allegheny or Cumberland Plateau, leading down into the Central Interior Lowland. Before the Appalachian Highlands were arched into their present altitude, this entire region was one vast and matured plain with slight slopes to the east and west of the central axis, which may not then have been higher than 500 feet above the sea. The subsequent arching up to the present level was not done at one time, but recurred again and again until the planed surface of the axial region stood over 2000 feet above sea-level. Above this plain, in North Carolina, the Black Mountains and other ranges stood as monadnocks, as they still do to-day. On the other hand, while this old plain was rising, the present trunk streams kept to their ancient valleys, corrading and entrenching themselves about as fast as the land periodically rose.

The whole of the New England states and the Maritime Provinces of southeastern Canada are continuations of the Appalachian Plateau, and all were elevated at the same time. Here, however, the plateau nature is even less evident, because the sedimentary rocks are greatly intruded by igneous ones, causing them to be variably hard, with the consequence that the dissection has been much more irregular, and the resulting topography is more rugged. The White and Green Mountains are monadnocks on this old plateau. Moreover, during the Great Ice Age, this region was heavily loaded with a very thick continental ice-sheet which accentuated its relief through ice erosion, and finally, because of the tremendous load of ice, depressed the whole of the plateau from 300 to 800 feet. After the ice had melted away, the land was deeply drowned, but soon began to rise, although it has not yet reached the altitude it had before the Ice Age. Accordingly the marginal portion of the plateau here remains partially submerged by the Atlantic, or, as the geologists say, the land is still drowned.

The oldest and greatest of North American plateaus is the Laurentian, extending from the Great Lakes and the St. Lawrence north to the Arctic. The first original flat surface here was made so long ago that we can have no adequate idea of its hoary age, and yet extensive parts of it remain to this day. Along its southern margin mountains have been raised and again worn away to a level confluent with the older Laurentian plain. Then seas of arctic origin repeatedly spread over a great part of it and laid upon it many hundreds of feet of strata which are now also almost wholly eroded away. Until geologically recent times, this old flattened surface remained standing

PLATEAUS, NEW AND OLD

Above, the Great High Plains, of comparatively recent elevation. Below, the old Appalachian Plateau in North Carolina. Photographs from the U. S. Geological Survey, by Darton and by Keith.

THE OLD LAURENTIAN PLATEAU

Note the low relief and the network of ponds and lakes. Photographed in Manitoba by Alcock, Geological Survey, Canada.

some hundreds of feet above the sea, but during the Great Ice Age it was down-warped in the Hudson Bay region, giving rise to the present bay, and elevated in the west to an average level of about 1000 feet, while toward eastern Labrador the plain had been raised, seemingly earlier, more than 2000 feet, with mountains along Davis Strait whose peaks are still between 5000 and 6000 feet above sea-level.

The shield during the Great Ice Age also underwent decided erosion due to the vast continental ice-sheets, changing into a rugged and exceedingly rocky country with hills that usually do not exceed 300 feet in height. Its drainage is still glacial in appearance and unlike that found in any other part of Canada, consisting as it does of innumerable ponds and lakes of the most diverse size and shape, spilling from one to the other by short streams in which rapids and falls up to 100 feet in height are

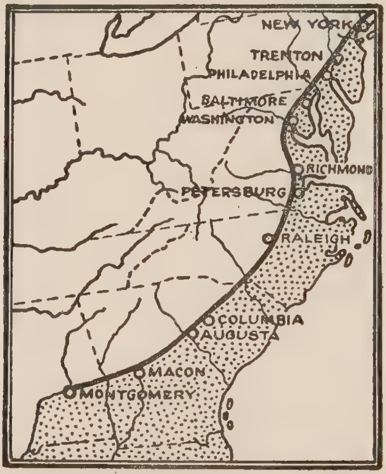
common. Only the larger streams, which occupy valleys of preglacial construction, have uniform channels. Seen from any commanding hill the numerous lakes, bare rocky hills and smooth, distant skyline are characteristic features.

South of the Laurentian Plateau and confluent with it is the most familiar of all our level areas, the low plateau embracing the middle western states and known as the Central Interior Lowland. For a long time seas oscillated back and forth over this region, and it was not permanently elevated above sea-level until the close of the third geological era (Paleozoic). How high it then stood is not known, but apparently between 300 and 700 feet. Then for the duration of the next two eras (Mesozoic and Cenozoic) it was subject to planation and eventually was reduced to a level that apparently stood nowhere more than 500 feet above the sea. Just before the Great Ice Age it took on its present altitude, which averages between 500 and 750 feet.

The most extensive of North American high plateaus is that called the Great High Plains. These lie east of the Rocky Mountains and extend from northern Mexico northward across Texas, eastern Colorado, Kansas, Nebraska, Montana, and the Dakotas (here about 800 miles broad), thence across Saskatchewan and Alberta and through the Northwest Territory to the Arctic Ocean. This region is in appearance truly a plain, but it has been elevated and hence is in reality a plateau. Along the eastern side of the Rockies in the United States the surface of this plateau rises to over 6000 feet above the sea, and everywhere it slopes eastward into the Central Interior Lowland and the Laurentian Plateau. It was ele-

vated to its present high stand some millions of years ago, but its surface is still remarkably smooth considering its elevation. (See figure on page 129.)

The highest, and scenically the grandest, of the plateaus of the United States is the Colorado Plateau, which lies in Utah, western Colorado, northwestern New Mexico, and northern Arizona. Its surface, lying between 5000 and 11,000 feet above the sea, is trenched deeply by rivers, and especially by the Colorado, whose Grand Canyon in northern Arizona, to be described in a subsequent chapter, is probably the most wonderful in all the world.



THE "FALL LINE"

After Tarr.

THE SEA: MAKER AND DESTROYER OF STRATA

CHAPTER XIII

SEAS, THE ACCUMULATORS OF SEDIMENTS

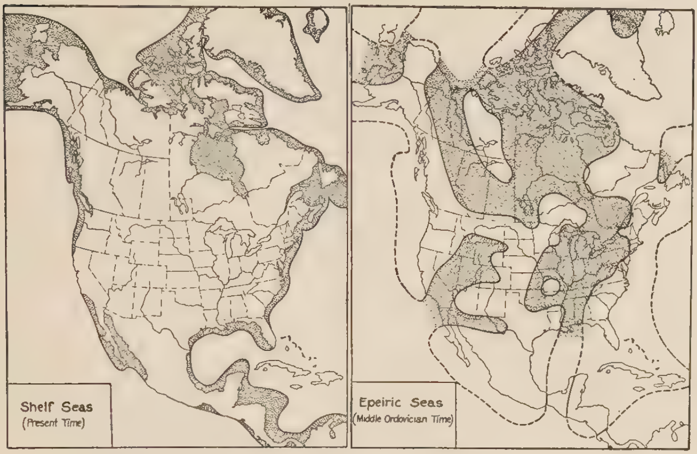
Everything in nature is engaged in writing its own history.—EMERSON

NATURE works in rhythms and in cycles, whether her immediate task be the production of river or mountain. The rain is born of the ocean, and to the ocean it returns when its work is done. The land rises into mountains at the behest of the mysterious inner forces of the earth, only to be dragged down once more by wind and rain until nothing remains but their roots. In obedience to the same forces, the oceans creep slowly in upon the lands, turn vast areas of them into shallow seas, and then ebb somewhat faster than they came. So it is with all the great earth symphony, once our ears are tuned to catch the recurrence of the varied motifs.

The story of the making of the sedimentary rocks presents no exception to this idea, with its repeated themes of erosion, transportation, and deposition; to make the cycle complete, however, there must be an interlude of land elevation to bring the sediments out of the sea again and resubject them to the weathering influences. We have in former chapters learned of erosion and transportation; now we have to consider the third factor, deposition.

The great majority of the sedimentary strata are of marine origin, because it is to the seas and oceans that nature's transportation systems bring most of the rock wastage of the lands. Only the accumulations of deserts and to a lesser degree the fresh-water deposits—the flood-plain and channel material of the rivers and the deposits of lakes—are laid down on the dry lands. The inland seas and the shallow waters of the oceans are therefore the final accumulators of nearly all the wastage of the lands, whether the sediments had their origin in alpine glaciers or beetling crags, in decomposing hillsides of corrading streams, or in the storm-beaten cliffs of the strand itself. It is here in the shallow waters of these great basins that the land waste is transformed into the well-stratified marine rocks which, as they solidify, seal up and preserve to us the remains of such animals and plants as lived at the time. Hence the marine strata are the most dependable recorders of the history of the earth.

At present the continents are everywhere bounded by shallow seas that are spoken of as shelf seas because in reality they lie upon the margins of the continents. They are rarely as deep as 600 feet and are truly parts of the continents, since it is only at their outer limits that the



SHELF AND EPEIRIC SEAS

The shelf seas that lie upon the present margins of North America, and the shallow epeiric seas that covered more than half of it in Middle Ordovician time. Recurrent seas such as the latter have laid down thousands of feet of sediments, in which are preserved the fossil records of the ever-changing marine life thus brought in from the several oceans.

rapid descent into the oceanic basins actually begins. Their total areas equal 10,000,000 square miles, which is after all only 5 per cent of the earth's surface, or 7 per cent of that of the oceans, and yet it is here that the main mass of the marine deposits of to-day is being made.

During most of geologic time, however, these shallow seas were not restricted to the borders of the continents, as we see them now, but, due to sinkings of portions of the lands, spread many times widely into their interiors. North America was thus flooded at least twenty times, sometimes in the eastern part of the interior, sometimes in the western, often extensively over the central low area,

MARINE ROCKS, NOW TWO MILES ABOVE THE SEA

Mt. Lefroy, Canadian Rockies, showing Cambrian strata originally laid down in the sea, but now pushed by crustal movements to a height of 11,600 feet above it. Note the glacier and terminal moraine in the valley. Photograph by Notman.

and once, in Cretaceous time, all the way from the Arctic to southern Mexico, and from the Mississippi River more than halfway to the Pacific coast. Into these wandering seas the ancient rivers emptied their burden of rock waste, and it was spread by currents throughout the extent of the basin, often far away from the oceans of today. These interior basins are known as epeiric seas (from the Greek word *epeiros,* which means continent), similar but smaller seas of the present time being Hudson Bay, the Gulf of St. Lawrence, and the Baltic Sea.

We may digress here a little to note that ever since the

days of the Greeks, the philosophers of many lands have puzzled over the petrified shells that are widely scattered over the continents. As these look like the shells living in the seas of to-day, the question: Can these petrified shells actually have been once alive? persisted in the minds of the thinkers. And if they were once alive, can their presence as petrifactions mean that the lands where they now occur have been covered by sea-water? The philosophers found these shells, moreover, not only on the lowlands and in the hills, but even in the highlands thousands of feet above the sea-level, and again they asked themselves: Can their occurrence here mean that the lands were raised out of the seas? A few of the Greek scholars dared to say that Malta and other places where such shells occur had formerly been beneath the sea, and had since been elevated out of its embrace. In the course of time more and more naturalists came to the same conclusion, but this knowledge of the few did not come to be the property of the many until about a century ago, first in England, then in France, although now all of the advanced peoples have made it a part of their everyday wisdom.

Granted, then, that the oceans have many times strayed from their present boundaries and spread over the face of the lands as shallow seas, how does the great amount of land waste brought down into these seas by the rivers accumulate there and become transformed into the beds of solid rock? We usually say in geology that the key to the past lies in the phenomena of the present, and accordingly the best method of finding out how stratified rocks have been made in ancient times is to see what takes place to-day when the rivers lay their burdens down in

the sea. The best place to begin such a study is in the deltas, which have the thickest accumulations, and then turn to the thinner but more widely spread and more typical marine deposits.

Nearly all of the large rivers of the present time have in their lower courses built up low flood-plains across which they meander leisurely toward the sea. As the momentum of the river slackens on nearing sea-level, the larger flakes of the material which it is carrying along in suspension drop to the bottom along the banks, and that which is being rolled along the bottom also comes to rest, the river bearing forward only the finest muds and sands and the salts that are in solution. If the river empties into a sea that is more or less enclosed and therefore does not have strong wave action, like the Gulf of Mexico, the current is greatly checked when it reaches the still water, and as soon as the fresh waters mingle with the saline ones, the smaller material in suspension is also precipitated to the bottom, where it eventually builds up a bar, or bars, across the mouth of the stream. The salts in solution remain in that state unless caused to precipitate out by the intervention of some other agency.

The growing bars finally obstruct the course of the stream and dam back the waters to such an extent that the river breaks through its banks farther inland and forms a new stream with increased grade. The new outlet then goes through the same process and thus, by building up banks and bars, and breaking through them, a branching system of distributaries is formed which has, roughly, the shape of the Greek letter *delta*. Between the distributaries lie very shallow basins of brackish or fresh water which gradually fill up with silt and eventually

become swamps replete with plants. These hold the muds and so build them up into dry land which in due course of time becomes forested. (See figure on page 52.)

The Mississippi delta is a very old one which began to form about 38 miles north of Cairo, Illinois, back in medieval time (Cretaceous). Since then it has gradually built itself out into the Gulf, through the "slow toil of Nature," for 1100 miles. The made land varies in width between 30 and 90 miles, narrowest at Natchez and Helena, widest at the mouth of the Arkansas River. In this sense the Mississippi delta has an area of over 38,000 square miles, though the delta proper occupies about one-third of that. It has, moreover, a known depth of at least 800 feet, showing that the area of the delta has sunk so much during its accumulation. The Nile delta, however, instead of subsiding, has kept on raising its surface and extending out into deeper waters, so that the city of Heliopolis, which lies thereon, has built itself higher by 25 feet in about 4000 years.

Deltas are sometimes formed in seas where there is considerable tide and rather strong currents, because their rivers bring larger volumes of sediment than these currents can carry away. Probably the most remarkable example of this kind is the Hwang-ho River of China, which has built out into the Yellow Sea a delta 400 miles long and from 100 to 300 miles wide, having an area of 100,000 square miles. This river, often called "China's Sorrow" because its fertile lowlands are swept by frequent floods such as that of 1887 which drowned or brought starvation to more than a million people, in 1892 shifted its mouth 300 miles to the north, and it has moved about in this way several times during the past few thousand

years. All of the flood-plains and deltas of rivers are thus subject to floods and disasters, but the floods also make more fertile the soils of these lowlands.

In deltas the dry land grows out into the sea at variable rates. One of the mouths of the Mississippi averages about a mile in sixteen years, but this is by no means the rate of growth of the whole delta front. The Rhone of France is spreading out into the Mediterranean about one mile in a century, and Rome, once a seaport, is now three miles inland on the Tiber River. On the other hand, the Nile delta has changed its submerged front but little in 2000 years because of the sweeping marine currents in the Mediterranean.

A delta always consists of two distinct parts—the landward, unsubmerged portion, with fresh-water deposits, swamps, and forests, and the submerged portion resting upon the submarine continental margin. The submerged part is under the sway of the sea and receives and spreads sands and muds brought by the river. Gradually more and more of the submerged margin is thus built up until it becomes a part of the dry land. On the outer side, the submerged portion is steadily pushed out into deeper water. Because of these conditions, deltas have marine beds that pass upward and landward into fresh-water ones, and when such areas periodically sink, as does the Mississippi delta, there will be formed a thick series of interbedded zones of marine, fresh-water, and swamp deposits, along with old soils. This has been proved by deep borings into various deltas.

Some of the deltas of earlier geologic time accumulated vast amounts of rock materials and subsided to depths of more than 10,000 feet during the time of their accumu-

lation. One such ancient delta in the Appalachian area extended from central Virginia to central New York, and where the Susquehanna River now cuts through its center we can see the total depth of strata deposited, which in Pennsylvania is 13,000 feet. The total mass of this delta is equivalent to a mountain range like the present Sierra Nevada of California.

Probably two-thirds of the marine deposits on the continents, however, are not the accumulations of deltas in quiet waters, since the land detritus is usually spread thinly and evenly over greater areas by the waters and winds of the seas. Moreover, most of the unloading rivers are small, and even when they are large the tidal and other currents may be so strong as to prevent thick accumulations at their mouths. The Thames, for example, forms no delta, because the strong tidal currents along the English coast distribute its burden far and wide. Nor does the mighty Amazon have a delta, for the same cause, but its sands and muds have built an extensive submarine platform covered with water less than 60 feet deep. The volume of water in the Amazon is so great that it carries mud out into the ocean for a thousand miles. Along the Atlantic coast of North America there also are no large deltas, but here the cause is recent subsidence, which has drowned all the river valleys and made of them shallow estuaries and bays like those of the Hudson and Delaware rivers and Chesapeake Bay. At the heads of these estuaries near the "fall line" the rivers have begun to build deltas, but as yet all of them are small.

Marine sediments will of course vary with the nature of the material furnished by the rivers and by the shore

cliffs, but they also vary in accordance with the portion of the seas in which they are laid down, whether near shore or some hundreds of miles out in deep water. As we saw in the earlier part of the chapter, the first material to be dropped by the river is that which is largest and heaviest, and the last to be retained is the finest and lightest—the muds along with the salts in solution. We may expect, then, to find the beds of coarser deposits nearest the shore in the most agitated waters, and those of the muds and silts farthest from it in the quieter areas. This is in general true. Hence near the shore, where the wave action is most powerful, we find the coarsest and most mixed of rocks, called conglomerates, which have not the homogeneous character of a sandstone or a limestone but are made up of rolled pieces of different kinds of rocks, held together by some sort of cement. They are often known as pudding stones. The conglomerates, moreover, may contain not only the river-borne material, but also many fragments broken from shore cliffs by the waves themselves. Here in the shallower waters, and those with strong currents, are also gathered the coarser sands, the material for the future coarse-grained sandstones. Beyond the reach of strong wave action, that is, in water deep enough so that the bottom is not greatly affected by waves (i.e., in depths below 250 feet), the detritus comes to be more homogeneous in character, and it is here that the fine-grained sands and the muds accumulate.

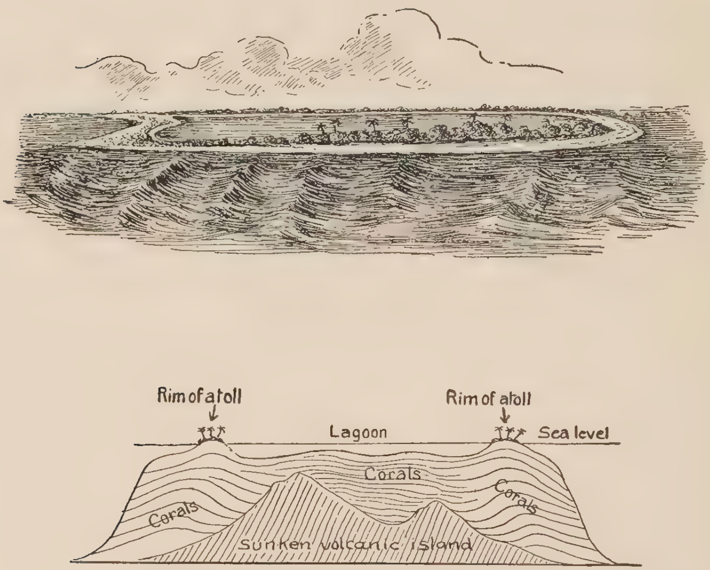
The final nature and location of the beds are, however, partly conditioned by two other factors, strong wave action and currents, which shift the material about, reassort it, and distribute it far and wide. When we

examine rocks in detail, we soon see that some of them are very thick accumulations of sands or muds, while the same kinds of materials occur elsewhere in thin deposits. In still other places the whole series is in thin layers that are alternations of sands, muds, and pebble beds, or muds and limestones. This comes about because the source of supply and the conditions of accumulation in one place remain constant for a long time, while in another they change frequently. When the waters of sedimentation are shallow and without powerful waves and currents, the deposits will pile up in thick beds of sands, or muds, as the case may be. With varying strength of wind and waves and currents, there is milling and sorting according to size, weight, and shape of grain, with the result that a thin bed of sand may have directly above it a thin layer of mud or of conglomerate, giving the whole series a layered or, as the geologists say, a stratified appearance.

As the sediments accumulate in greater and greater thickness, the superposed load squeezes out the sea-water more and more, and finally there will be so little left that the cements that have been in solution, like carbonate of calcium or magnesium, silica, and oxide of iron, will "set" and so consolidate muds into shales, sands into firm sandstones, and pebble beds into conglomerates. It is at best a very slow process, taking much longer under the sea-water than do the accumulations on dry land.

So far nothing has been said about limestones and chalks, because into their formation enters another factor, namely, life. Hence geologists speak of them as organic deposits. In the evolution of marine animals, one of the

great adaptations was the discovery of how to extract calcium carbonate from water in order to produce hard protecting shells. This calcium carbonate is brought to the sea in enormous quantities by the rivers in the form of the soluble bicarbonate, $H_2Ca(CO_3)_2$, and is converted



A CORAL ISLAND, OR ATOLL

Islands such as these are built up in the ocean by the accumulating skeletons of countless tiny animals.

by the water-living plants and animals into the normal insoluble carbonate ($CaCO_3$) of their shells and skeletons, which goes to make beds of limestones as the organisms accumulate after death. The greatest amount of this work is done by small animals known as foraminifers, which are the essential chalk-makers, and by shelled

animals, such as molluscs, while the great limestone reefs that are so marked a feature of the tropical oceans are built up largely by myriads of little plant-like coral animals, working through countless years.

Certain exceedingly minute plants, bacteria and other similar forms, which exist in incredible abundance in the oceans, also contribute indirectly to the making of limestones by producing ammonium carbonate in the course of their life processes, which, acting as a precipitant upon the calcium bicarbonate in the water, throws it down to the sea bottoms as lime.

VISHNU TEMPLE

CHAPTER XIV

THE GRAND CANYON OF ARIZONA: NATURE'S BOOK OF REVELATION

What force has formed this masterpiece of awe?
What hands have wrought these wonders in the waste?
O river, gleaming in the narrow rift
Of gloom that cleaves the valley's nether deep,—
Fierce Colorado, prisoned by thy toil,
And blindly toiling still to reach the sea,—
Thy waters, gathered from the snows and springs
Amid the Utah hills, have carved this road
Of glory to the Californian Gulf.

—Henry van Dyke

THE Grand Canyon of the Colorado, because of its mysterious and awful beauty, is a Mecca for travelers the world over. To the pilgrim who seeks to learn the meaning that lies behind the beauty, it has, moreover,

a very special allure. For here as nowhere else Nature has chosen to reveal, as in an open book, the ways in which she has built up this earth of ours, only to tear it down and rebuild on the ruins.

So far as its geologic history is concerned, the Canyon does not differ from other great gorges, inasmuch as it has been cut by a river through the rocks of a recently elevated plateau. Its great size and extraordinary beauty are, however, the result of an unusual combination of circumstances. In the first place, the strata making the upper 3500 feet of the plateau, although laid down in very ancient seas, are still in their original horizontal position and unaltered by the hardening effects of crustal disturbances, so that they offer comparatively little resistance to erosion. Long after they were deposited, the elevation of the whole region at least 7000 feet steepened the grade of the Colorado and its tributaries and these were, furthermore, abundantly supplied with water from the great snowfields of the Rocky Mountains during the time of the Great Ice Age. Given, therefore, a comparatively unresistant medium and a greatly strengthened tool, aided by the powerful weathering forces of an arid climate, and the result is the most marvelous series of canyons in all the world, with a total length that exceeds 500 miles. These canyons are nearly everywhere impassable, and with their inhospitable desert bottoms and roaring river form a barrier to human travel more effective than the Rocky Mountains.

The Colorado Plateau in the area of the Grand Canyon slopes southward about 100 feet to the mile. Accordingly the north rim of the Canyon is higher by about 1000 feet, and it is three times as far from the river as

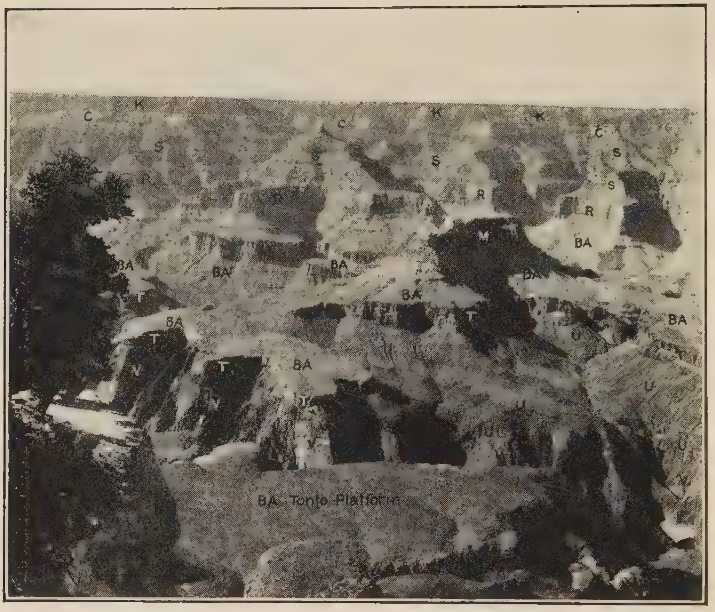
the south rim. Far more snow and rain fall upon it, and hence it has perennial springs and streams that have helped to carve deep gorges, or extended "amphitheaters," separated by long promontories which are dissected into fantastic buttes and "temples"—"mountains of erosion" carved out of the horizontal strata of the plateau. The south wall, on the contrary, dry because its ground-waters flow away to the south, is far less sculptured and has but few buttes and no great amphitheaters; it is precipitous and the scenic effect is somber and terrifying.

The south wall of the Grand Canyon about Bright Angel descends step-fashion by cliffs, steep slopes, and narrow ledges for 3000 feet. Next comes a wide terrace, the Tonto Platform, which is so continuous that one may travel along it for at least 50 miles. Beneath is a dark-walled V-shaped gorge about 1200 feet deep, at the bottom of which flows the rapid Colorado, still busy at its task of eating down to sea level. The Canyon therefore has an upper, wide and older, fantastically sculptured, and brilliantly colored valley, carved in soft rocks, and an inner, much narrower, and somber gorge that is cut in dark and very resistant ones. This inner and younger chasm is the Granite Gorge, taking its name from the fact that granite is scatteringly found throughout it.

The nature of the rocks below the plateau is openly revealed in the walls of the Canyon, where the edges of the various rock formations extend for tens of miles as so many huge colored bands which in descending order are yellow and white, red, and finally olive green. These rock colors are not constant throughout the day, but change greatly with the height of the sun and the presence or absence of clouds. Finally every slope and platform

Photograph from Fred Harvey.

GRAND CANYON OF THE COLORADO RIVER, ARIZONA



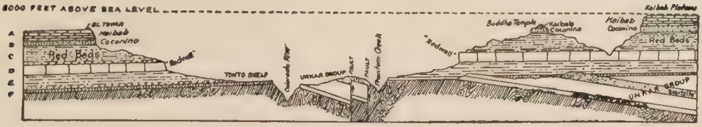
GRAND CANYON, FROM YAVAPI POINT

K=Kaibab limestone.
C=Coconino sandstone.
S=Supai sandstone and shale.
R=Redwall limestone. } Paleozoic.
M=Muav limestone.
BA=Bright Angel shale.
T=Tapeats sandstone.
U=Unkar group. } Proterozoic.
V=Vishnu schist.

Compare with the geologic section. Photograph from Fred Harvey.

has scattered trees and bushes of dark green colors, so that the total effect is beyond description either by pen or brush.

The rock formations lie level or nearly so, and closer examination shows that the cliff-makers are yellow and



SECTION ACROSS GRAND CANYON WEST OF BRIGHT ANGEL CREEK FROM EL TOVAR TO KAIBAB PLATEAU

A Kaibab Limestone
B Coconino Sandstone
C Supai (Red Sandstones and Shales)
D Redwall Limestone
E {Shales, Sandstone} Tonto
F Granite, etc.

RELATIONS OF THE ROCK FORMATIONS IN THE GRAND CANYON

To be compared with the photograph taken from Yavapi Point. Note how the ancient beds of the Unkar group, to the right, have been tilted from their original position, so that they now lie at an angle with the beds above. In other parts of the Canyon, these Unkar mountains have been worn entirely away, and the Tonto rocks lie directly upon the granite of the inner gorge. After Darton.

red limestones, and muddy red and cleanly washed yellowish white sandstones, while the red and green mudstones make up the slopes. The total thickness of the strata down to the base of the wide Tonto Platform is over 3500 feet, and as the seas that deposited them were shallow, it is evident that during the time of their deposition, the third geologic era (Paleozoic), the whole region subsided to at least that depth. The sea was not, however, present continually, but came in at least five different times from the Pacific, spread widely, stayed for a long time, deposited at each recurrence many hundreds of feet of strata, and then as often withdrew to the Pacific. The region therefore sank at least five times beneath sea-level and then rose above it as often into dry land, but in the end the sum of all the movements was downward to the extent of 3500 feet.

Beneath the stratified rocks of the third geologic world (Paleozoic) which make the terraced walls of the Canyon, and above the rocks of the Granite Gorge represent-

ing the first world (Archeozoic), there lie the ruins of the second world (Proterozoic), a long sequence of strata known to geologists as the Unkar and Chuar formations. They have a united thickness to the east of Bright Angel of 12,000 feet. Some of these strata of the second world can be seen from the south rim in front of the hotels or anywhere between Hopi Point on the west and Grandeur Point on the east. Looking to the northwest from Hopi Point, there is not a trace of them to be seen because here the third world rests directly on the first one, but to the northeast, in front and on either side of Cheops Pyramid, lie the bright vermilion mudstones and dark brown sandstones of the Unkar formation. Here, however, there is a thickness of only 1000 feet, all the rest having been removed before the third world came into existence. The farther we go to the eastward in the Canyon, the more we see of the Unkar and Chuar rocks, while to the west they are usually removed through erosion, and all of this before the strata of the Tonto Platform were deposited.

If we look again at these red rocks of the second world, we see that they are tilted to the northeast. This structural condition means that after their deposition they were tilted into a mountain range not less than two miles high, and yet a view to the northwest reveals nothing of them, because they have been eroded away and even much of the older ground upon which they rested has been planed across. It is this plane, now represented by a horizontal junction line, that we see above the Granite Gorge and upon which were laid the strata of the third world, those making the Canyon's terraced walls. Such a junction plane between two sets of differently disposed

rock formations—the lower older crumpled series of the Granite Gorge with the higher and younger horizontal strata of the third world resting upon its planed surface—is called an unconformity, and means the loss of one or more worlds of strata through erosion.

The schists and granites in the Granite Gorge are crystalline rocks that have been highly altered, crumpled, and folded. Some of them were water-laid, and these are of great interest because they are among the oldest such rocks known on the face of the earth. Originally these sediments were laid down horizontally, but long after their origin they were bent and folded into mountain ranges and then twice intruded by granites and other molten rocks. Hence they are now much altered and changed into schists, or, as the geologist says, are much metamorphosed. Then for a very long time they were subject to erosion, and this work of destruction went on until at least the whole area of Arizona and Utah was reduced to a nearly level plain. What is left of these rocks forms the record of the first geologic world, the Archeozoic era.

Another of the interesting features of the Canyon is its very recent and small volcanoes, which, curiously, instead of breaking through in the depths of the Canyon have done so upon its very rim. Their lavas have flowed in small volume down the walls, showing clearly that the little volcanoes are younger than the canyon. They take on a far greater meaning when it is recalled that on the Colorado Plateau 50 miles to the southeast of Bright Angel and El Tovar hotels stand a group of large volcanoes, the San Francisco Mountains, which, through the extrusion of ash and lava, have piled themselves about

5000 feet above the plateau and now stand nearly 13,000 feet above sea-level.

So far we have been observing in the main the destructive forces of nature as shown in the Grand Canyon, but the walls of the Canyon are even more significant in showing her constructive activities. Standing on its brink and looking down the walls of the Canyon and inner gorge, we are actually looking almost the whole length of the corridor of geologic time. What a vast vista this is in time as well as in space, for the magnificent work that lies beneath our view has taken not less than hundreds of millions of years to create!

To make this stupendous fact comprehensible we must turn to the Canyon's geologic history. First, the oldest rocks known to geology (Archeozoic), those of the Granite Gorge, had to be made, elevated into a mountain range, and worn completely away to a level land. This history is seen in the crumpled condition of the rocks, which were invaded by granites and planed across before another constructive period began; this consumed 30 per cent of geologic time. Second, upon this very ancient level floor were deposited 12,000 feet of essentially red rocks, in the main of continental origin, which were then tilted to the east and thus made into another mountain system. Like the earlier ones, these mountains were also completely worn away, and the area planed across to a level land. All this was done during the Proterozoic era, occupying another 25 per cent of geologic time. Third, the Pacific Ocean flooded the area at least five times and deposited the 3500 feet of strata that now make the wondrous walls of the Canyon; this consumed 30 per cent. Fourth, during the fourth geologic era (Mesozoic),

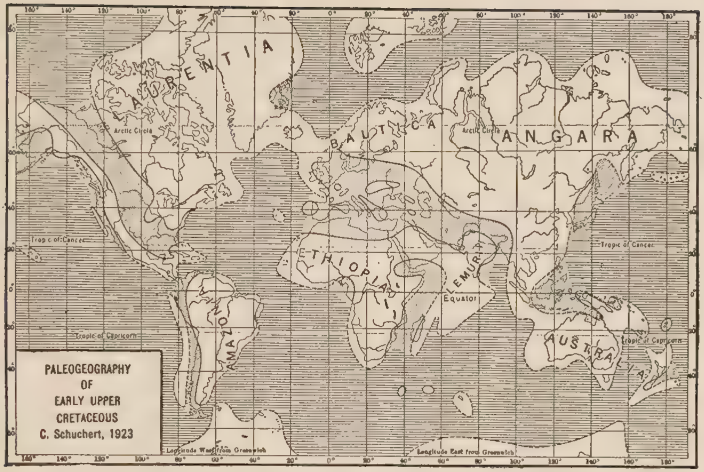
the area was flooded at least once by the Pacific, leaving strata which, with the added younger fresh-water deposits, may have been 2000 feet in thickness (11 per cent), but which are now all eroded away from the immediate area of the Grand Canyon. Then came the pushing up of the Rocky Mountains, though Utah and Arizona do not seem to have been elevated more than a few thousand feet. Fifth, for a very long time (most of the fifth or Cenozoic era, 3 per cent), erosion followed, developing a plain that was subsequently tilted to the south to form the Coconino Plateau over which the traveler comes from Williams to Bright Angel. Up to this time, the period of the "great denudation," there was no Grand Canyon, but over this plain, eroded almost to sea level, the Colorado River flowed lazily to the Gulf of California.

Sixth, there began the vertical elevation not only of the Rocky Mountains and the Sierra Nevada, but of the intermediate area as well, from southern Mexico into Alaska. When completed, this mighty crustal movement brought on, mainly because of the high altitude of the land, the Great Ice Age, which accentuated the falling of snow and water in the high mountains, and through the greatly increased stream gradient, heightened markedly the flow and corrasion of all the rivers. As soon as the land began to rise, the Colorado River and the weathering influences began a new cycle of corrasion and erosion, and together they started making the upper part of the Grand Canyon. This work was continued with great force all through the Great Ice Age. The cut through the upper sedimentary rocks was probably made fairly rapidly, but the work of tearing a passage through the granites below the Tonto

Platform was accomplished more slowly. How long it has been going on, stated in years, it is impossible as yet to estimate, but certainly more than one million. The river will continue its corrasion until its grade is but little above sea-level, and in the meantime the Canyon walls will slowly erode into longer and gentler slopes. When the western highlands are worn lower and lower, more and more rain will be carried farther and farther east and the whole of the Colorado Plateau will evolve into a rugged mountain country.

Standing again on the brink of the Grand Canyon and looking down into the labyrinthine maze of gorges, we see something of the destructive work of nature accomplished during the past million years, but the walls of the Canyon themselves reveal something far greater, namely, the constructive work done through almost all of the earth's history. This wondrous scenic grandeur therefore becomes all the more significant when we understand the genesis of the rocks which tell of vast geologic times, indeed so vast as to be beyond our finite understanding.

How far beyond all language and all art
Is thy wild splendor, Canyon Marvellous,
The secret of thy stillness lies unveiled
In wordless worship! This is holy ground,—
No grave, no prison, but a shrine thou art.



CRETACEOUS GEOGRAPHY

Lands white, oceans ruled, epeiric seas dotted.

CHAPTER XV

THE CHANGING FACE OF THE EARTH

ONE of the greatest truths in geology is that the geography of the earth is constantly undergoing change, due mainly to the fact that the surface of the lands and the oceanic level are at times in decided motion: "ages and cycles of Nature in ceaseless sequence moving." These crustal oscillations are not caused by heterogeneous and unrelated movements, but are connected, in that areas of elevation and depression remain as such during more or less long stretches of geologic time. Not only do the lands move up and down, but it is now also clear that the ocean bottoms are periodically more or less in motion. The movement of the ocean waters may be of small and narrow extent, due to local warpings of the surface, or may spread over areas of great magnitude in

consequence of marked crustal deformation and the filling of the oceans with land detritus. Nevertheless it is generally agreed by geologists that the oceanic basins and the continents have been in the main permanent features in the earth's geologic history; the oceanic basins are regarded as vast sinking fields—negative areas—because of their heavier rocks, while the continents are rising masses of lighter rocks, or positive areas.

The cause for this unrest in the earth's crust is a vexing problem that has engaged the attention of geologists since the early days of the science. The explanation has long been thought to lie in the shrinkage that resulted as the earth continuously cooled down from a molten condition. This is the orthodox opinion and yet it has never been clearly demonstrated. However, our growing knowledge of the part played by radium in the earth's history, due to its continuous disintegration in the rocks and the heat thereby generated, opens up new vistas, and it may be that periodic crustal movements result rather from some such cycle of events as the following: (1) The accumulation of radioactive heat in the basaltic shell until the latter finally attains the melting point, with a consequent increase in volume which in turn swells to a small extent the circumference of the earth; (2) the gradual radiation of this heat out through the oceans; and (3) the return of the basalt to the original solid condition, with consequent decrease in volume and necessity for crustal adjustments. In other words, swelling and shrinkage of the earth are probably the primary cause of crustal unrest, but these are periodic, not constant.

The oceans, as we have seen, are the beginning and end of the rivers of the lands. The word ocean is of Greek

origin, and came to mean the great outer ocean, the Atlantic, as distinguished from the internal sea, the Mediterranean. The word now, however, has reference to the five widely connected bodies of marine water that together occupy nearly three-fourths of the earth's surface.

The mediterraneans, on the other hand, are elongate and less deep basins that are almost enclosed by the continents but have one or more outlets to the oceans. The typical example, the Roman mediterranean, lying between Eurasia and Africa, figured much in the geologic history of the earth as a far greater body of water, continuing eastward through Asia into India and Burma and thence into what is now the eastern Indian Ocean. This greater mediterranean is called Tethys after the consort of Oceanus.

The mean depth of the oceans is placed at 12,000 feet, and the volume of all the oceanic waters is fifteen times greater than the mass of land protruding above sea-level. If all the deeper parts of the oceans were filled by solid material up to the mean depth, it is said that there would result a universal ocean, covering the entire earth to a depth of 1.5 miles. Put in another way, if the land masses now above sea-level were transferred to the oceans, the general level of the latter would be raised about 650 feet. These facts show, since the waters are mobile and cover nearly three-fourths of the earth's unstable surface, why it is that the oceans are enabled so readily to overflow the lands upon relatively small changes in the elevation of the crust. As the oceans are all connected, a movement of the bottom of any one basin affects the oceanic level in all, raising or lowering the strand-line everywhere simultaneously.

Where did all of the immense volume of oceanic water come from? Originally it was said to have come with the creation of the earth, but since all volcanoes when

THE CANADIAN SHIELD (BLACK), OLDEST PART OF THE NORTH AMERICAN CONTINENT

in action are replete with steam, it is now held that all of it came during the past geologic ages from the inner hot earth, either through volcanoes or hot springs. In other words, the earth has actually generated its own oceans.

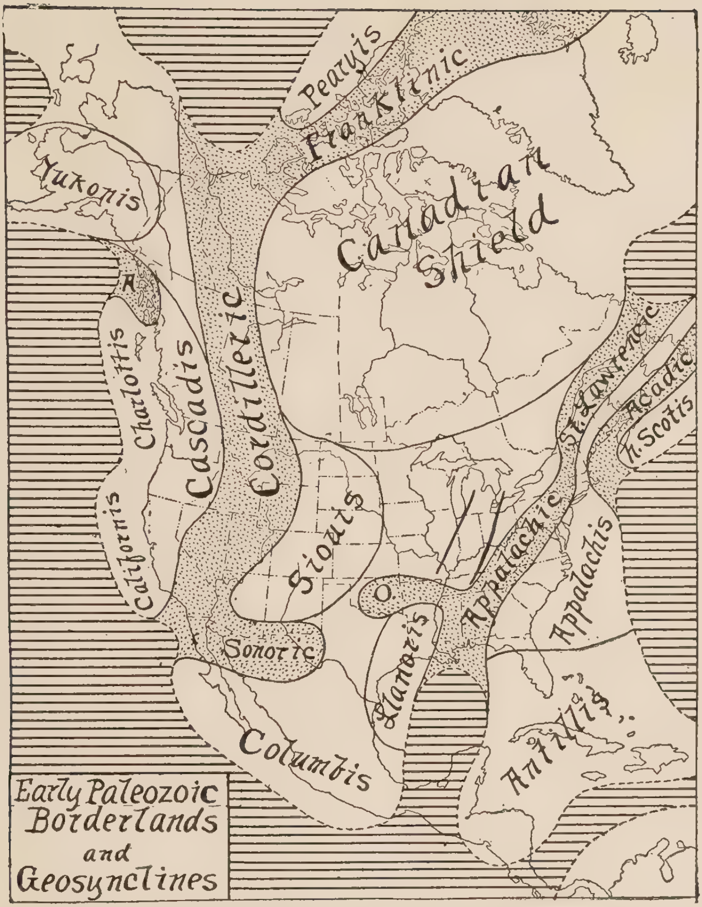
To man, the lands are beyond doubt the most important parts of the earth's surface, despite the fact that they occupy but 30 per cent of it, for these relatively small areas—the Pacific alone is greater by 10,000,000 square miles than all the continents combined—have furnished the setting for the most striking scenes in his evolutionary history. A continent is a large body of land having a distinctly basin-like form, the rim being the mountain chains on either side of the low interior. North America has this form in its simplest development, with a somewhat triangular shape; South America has lost its eastern margin; Africa now lacks both the western and eastern rims; and Eurasia consists of at least two continents welded together.

Most of the present continents have been formed around very ancient protuberances—Emerson's "primeval, immovable cornerstones of the earth." The name "shield" has been applied to these, because the best known one, the Canadian nuclear mass, sometimes called Canadis, has the form of a depressed shield. This old nucleus came into existence very early in the history of the earth, and all of its mountains and highlands were worn away to plains before North America took on its present shape. The rocks of Canadis are now more or less decidedly deformed and changed, because of vast granitic masses that welled up hot into the sediments and elevated them into either mountains or high plains. Being the oldest rocks, they have been longest subject to erosion, and in them we therefore look, as it were, miles deeper than elsewhere toward the heart of the earth's crust.

As we have just seen, it is when the continents subside

that the oceans spill over them, and when they rise the seas are dispelled. This flooding is especially marked in long and narrow tracts toward the margins of the continents, which during the geologic ages slowly subside tens of thousands of feet. These sinking tracts, which are called geosynclines, are evidently areas of weakness in the crust. While sinking, they let in the oceans repeatedly, and as they receive the wash from the adjacent highlands, they become filled up with sediments about as fast as they subside. Finally the areas of the geosynclines are pushed together into folded mountains by horizontal pressures coming from the oceanic areas, while other subsequent vertical pressures arising beneath the continents reëlevate them time and again. Outside, or oceanward, of the geosynclines are periodically rising land masses called borderlands, which furnish the sediments to fill the sinking geosynclines. A further interesting fact in connection with North America is that its borderlands once extended hundreds of miles into the oceans beyond the present shore lines, and it is into the oceans that they have largely sunk.

It is now known that the oceans have spread periodically and more or less widely over the North American continent at least twenty times. In a broad way it may be stated that the floods begin and end with shelf seas marginal to the continent and occupying between 1 and 5 per cent of those slightly submerged areas known as the continental platforms, the conditions thus being not unlike the present conditions of overlap; while the greatest inundations are of the interior or epeiric seas that cover from 12 to about 50 per cent of the continent. There is a certain amount of rhythm in these movements,



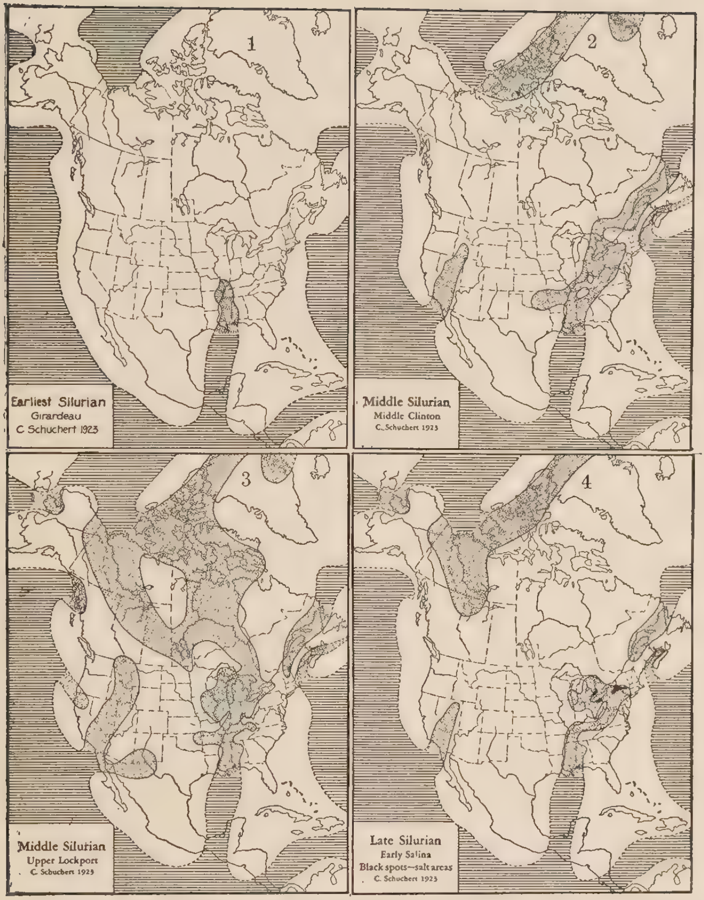
NORTH AMERICA IN EARLY PALEOZOIC TIME

Persistent sea-ways or geosynclines are dotted, outside of these are the rising borderlands or geanticlines, and in the center is the ancient nucleus of the continent. Antillis is also an old land. The black lines to the south of the Great Lakes represent other axes of elevation.

and this has been used, as we shall see later, to divide the geologic sequence into systems of rocks or periods of time.

Under the waters there is continuous sedimentation, and they abound in more or less of evolving life that is most advantageously situated for burial and preservation; hence the marine stratigraphic sequence is the least broken of the several kinds of historic records accessible to geologists. It is therefore apparent why the major portion of the earth's chronology depends for its determination upon the marine sediments. These sediments, except in so far as they are later eroded, record the extent of the transgressions, and something of the topographic form of the adjacent lands, with a hint as well of their climates; and through their entombed life they establish not only the chronology from place to place, but the sequence of time everywhere on the earth as well.

Geography has to do with the present configurations of the earth's surface, but what we see to-day is the resultant of very many changes during the geologic past. The desire of geologists to unravel the procession of these ancient geographies has led them to the making of what are known as paleogeographic maps (from the Greek word *palaios*, meaning ancient), such as depict the probable outlines of the lands and seas during a given time of geologic chronology. The set of four of these maps snown on the opposite page pictures the transgression of the sea over North America in Silurian time, beginning as a small invasion from the Gulf of Mexico, which steadily spread to join a similar sea coming in from the northeast, the two combined lying in the area of the so-called Appalachian geosyncline. In the meantime seas



A CYCLE OF MARINE FLOODS

The coming and going of the seas over North America within one geologic period, the Silurian. Maps such as these are made on the basis of the geographic distribution of sediments known to be of the same age because of their entombed fossils.

pushed in from the Arctic and the Pacific, so that by the middle of the period about 40 per cent of the continent was under water. As gradually as they came these floods retreated, until the end of Silurian time found the land again entirely above the water, save for a very slight area where the Gulf of Mexico first began its encroachment.

Photograph from O'Harra.

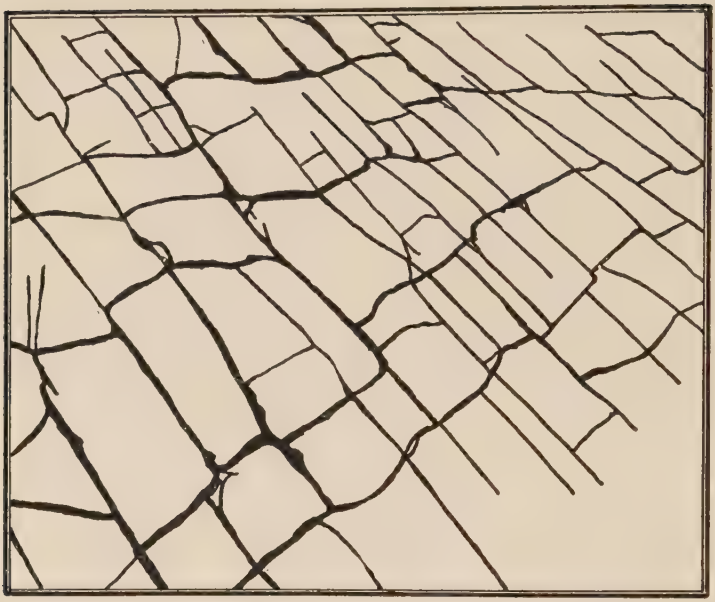
PILLARS MADE BY THE JOINTING AND WEATHERING OF GRANITE
CUSTER PARK, S. D.

CHAPTER XVI

THE FRACTURING OF THE EARTH'S SURFACE: EARTHQUAKES

. . . a worn, ancient face, seamed, stained, and engraved with endless cross-hatching of documentary wrinkles.—C. E. MONTAGUE

WHEREVER we examine the consolidated rocks of the earth's surface we see that they are intersected by systems of cracks and thus broken into blocks of various sizes and shapes. This fracturing is most conspicuous in quarries, or in the cliffs along streams and in the mountains. It is, moreover, not restricted to the immediate surface of the earth, but is also met with in mines, where it enables the workmen the more easily to quarry out the materials. This condition is believed to extend, with decreasing importance, down to about 12 miles beneath the surface, where the pressures begin to



JOINT PATTERN IN ROCKS

Rocks generally break apart along systems of cracks running at right angles to each other, as in the pattern here shown. If this pattern of lines cuts deeply down through the rock, the resulting blocks will be more or less rectangular in shape, as in the following figure.

be so great that fracturing is probably impossible. Therefore geologists speak of this outer part of the crust as the zone of fracturing.

The outer part of the earth is thus more or less abundantly and deeply fractured, or, as the geologist says, is jointed. In stratified rocks this cracking runs in all directions, but commonly in two systems nearly at right angles to each other, varying from almost invisible cracks to large open fissures. The acidulated rain water enters

ROCK JOINTING

The extension downward of surface cracks in rock produces rectangular blocks like those here depicted in the Sherburne flagstones at Ithaca, New York. After Kindle.

these cracks and helps to widen them through solution, and to break down the rocks into soils, and by means of them the ground-water is enabled to circulate from joint

to joint and to escape at lower levels as springs. Since the waters thus circulating through the rocks contain solution materials, these may crystallize out and fill up the more deep-seated joints with mineral matter, or make veins of valuable ores. Or hot waters, with even greater amounts of dissolved materials, may come from deep within the earth through these joints, and fill them with other kinds of minerals and ores. The mining industry is therefore deeply concerned with the nature of the joint systems, the kinds of rocks they traverse, and whether cold waters have descended into them, or hot waters have come up into them from below.

Commonly there are in horizontally disposed strata at least two sets of vertical joints that cross each other nearly at right angles, but in addition there may be other systems traversing the rocks more or less horizontally or diagonally, thus breaking them up into regular or irregular pieces or blocks. The spacing of the joints and their depth and length are exceedingly variable. There may be a great abundance of tiny cracks with larger and larger ones interspersed, or there may be only large ones which can be traced hundreds or even thousands of feet along the surface, while in the Grand Canyon individual ones can be followed to depths of many hundreds of feet, making the vertical cliffs. Such major joints are usually remarkably straight and with fairly smooth faces which may be in contact with one another or may gape more or less. They tend, however, to be widely open at the surface, because of weathering.

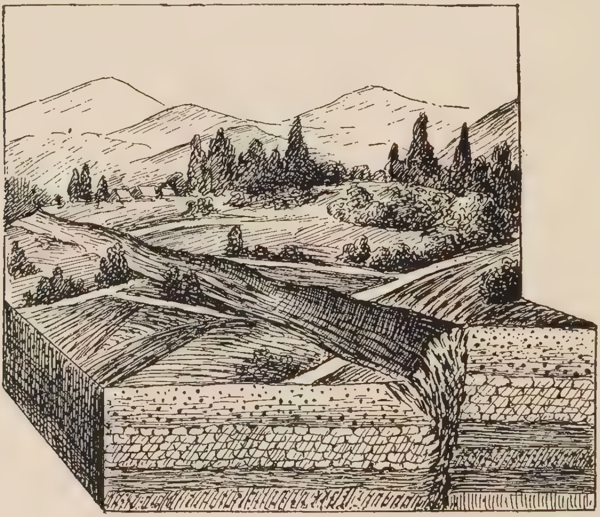
Undoubtedly sedimentary rocks, while consolidating through the loss of water taken up at the time of deposition, shrink without cracking, and are cemented to-

gether, but when they once have become set, further shrinking can take place only through jointing. When mountains are made, for instance, their rocks, because of the great pressures, are shrunk in one direction and stretched in another. On the other hand, all molten (igneous) rocks shrink and split on cooling, and this fact is beautifully shown in the columnar jointing of lavas or of deep-seated basalts like those of the Palisades of the Hudson River (see figure, page 47), or the Giant's Causeway of Ireland. All rocks expand more or less with increase of temperature, and the more violent such changes are at the surface of the earth, the greater will be the stresses and strains set up in the rocks and the amount of jointing. Undoubtedly in this way much of the minute surficial cracking is brought about, and probably also some of the deeper jointing, but on the whole most of it is believed to be caused by crustal movements, as will be explained later.

All of the smaller fracturing that divides the rocks into blocks is embraced under the term joints, and when these become significant enough so that single ones can be traced through hundreds or even thousands of feet, they are called fissures. In all of these there is, however, no appreciable displacement of the rocks on either side of the joint or fissure, but when displacement occurs due to the rising or sinking of one side or the other, or to moving in a horizontal direction, the rocks are said to be faulted, and the line of movement or fracture as seen at the surface becomes a fault-trace. Such lines of displacement on the surface of the earth are of very great significance in geology, since during their growth they mark the places from which most earthquakes start. The California earth-

quake of April 18, 1906, was due to a sudden movement of the San Andreas fault, one side of which slipped anywhere from 7 or 8 feet to 21 feet horizontally and (locally) from 1 to 3 feet vertically; this fault-trace can be followed over the ground for 600 miles, but the displacement of April 18 occurred only along the northern 270 miles of it. Usually, however, the movement on a fault-trace is less than 50 miles.

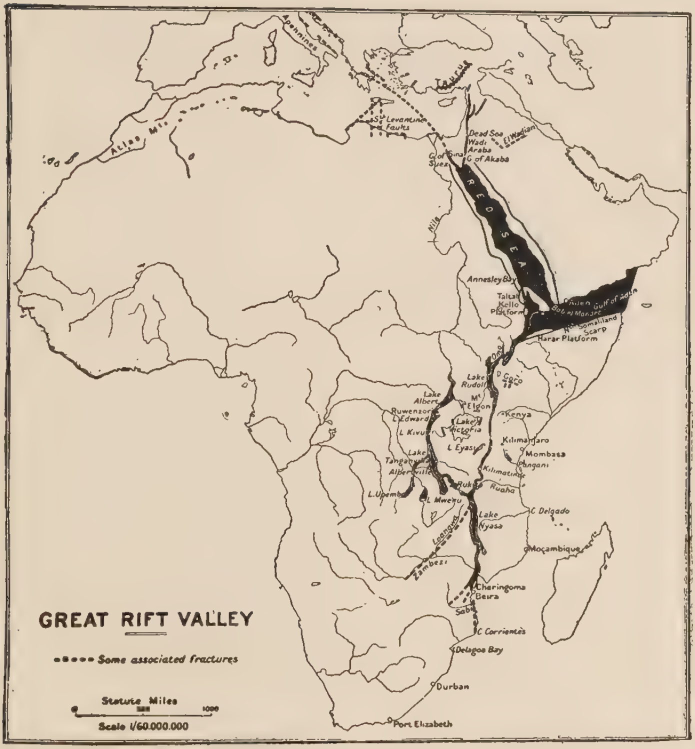
The plane along which the displacement occurs is rarely exactly vertical, and may, in the areas of folded and thrusted mountains, approach horizontality. When this



FAULT DIAGRAM

Faults (geologically speaking) occur when rocks break through and one side of the fracture drops below the other or moves horizontally. Earthquakes accompany these dislocations of the crust, and the drawing shows, somewhat diagrammatically, a vertical slip along the fault-line during the Japanese earthquake of October 28, 1891. After Sieberg, in Salomon's *Grundzüge der Geologie*.

plane is at a low angle, or almost horizontal, one mass will be shoved over and ride upon the other, making what



THE GREATEST KNOWN SYSTEM OF "RIFT VALLEYS"

These troughs were not worn out by rivers, but formed by the sinking of blocks of the crust. They are due to faults caused by earth movements—a form of unrest with which Africa and Asia Minor are peculiarly afflicted. After J. W. Gregory.

is called a thrust-fault. The movement at any one time is comparatively slight, but may be tens of feet. Commonly it is only a few feet, and displacements along a

THE QUEBEC OVERTHRUST

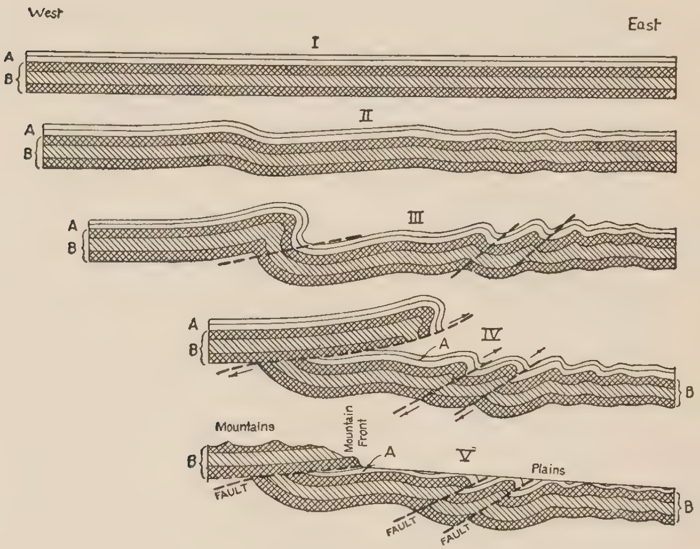
The citadel owes its commanding position to an overthrust mass shoved many miles from the southeast over horizontal strata that lie beneath the St. Lawrence River. Photograph by Notman.

given fault-trace may follow one another tens or even hundreds of years apart. They continue periodically, however, through untold geological time, and in the end the vertical displacement may total several miles, while the overthrusting may attain tens of miles. Where one side of a fault drops far below the other, great fault-scarps result, making cliffs or declivities thousands of feet high, and in hard rocks these develop much more quickly than erosion can remove them. The fault-scarp of the Wasatch Mountains near Ogden, Utah (see figure, page 221), is such a one; it is believed to be in motion even now. The great eastern face of the Sierra Nevada is an even greater example, its fault-scarp in Owens Valley standing about two miles high. The Great Basin region shows normal faulting on a colossal scale, since the entire area between the Sierra Nevada on the west and the Wasatch on the east is divided into huge blocks by fractures that are in places a hundred miles in length. An even greater fault area lies in eastern Africa and southwestern Asia, where sunken "rift valleys" with their long and deep lakes, Tanganyika and Nyassa, extend from the Jordan Valley and the Red Sea south to the Zambesi River, a distance of about 3500 miles.

Great fault movements are also recorded in the rocks in areas where there are now no fault-scarps; such, for example, was the faulting in Triassic time along the eastern side of the Connecticut Valley, with a vertical displacement of about two miles.

In most of the folded mountains, thrust-faulting is common. An older mass of rock may here be pushed over younger ones for thousands of feet, and not uncommonly for several miles. In the Appalachians and in the

Rockies, thrust masses have been pushed to distances of 10 to 25 miles or more and in the western mountains along fronts of at least 270 miles. Even greater horizontal movements of such overriding masses have occurred in the Scandinavian Peninsula and in the Alps.



OVERTHRUSTING

Diagrams to show what happens during the geologic process known as overthrusting. From Campbell, *Origin of the Scenic Features of the Glacier National Park,* published by the Department of the Interior.

Much of the rugged mountain beauty of the eastern portion of Glacier National Park is due to the great Lewis Overthrust, which is in turn but a small part of a tremendously long block of the earth's crust that has been shoved from the west so as to override younger rocks to the east. This vast dislocation was brought about by

great pressures from the west, pushing the rocks of the Park area against an unyielding segment of the crust far to the east. Thus caught between an irresistible force and an immovable mass, the rocks of the intermediate region had to "give," with the result shown in the series of diagrams on the opposite page.

Before the movements began, the rocks lay horizontal, as in I, with *A* representing the younger, softer strata, and *B* the harder, more ancient limestones. When the pressure from the west first began to be felt, relief was gained by a slight rippling or folding, as the rocks were crowded into a smaller space (II). The pressure continuing, the folds grew higher, especially the westernmost one, which eventually began to tip over toward the east (III). Finally, as this overfolding increased, the elasticity of the rocks reached its limit and they broke through at the bend (black dotted line of the diagram), leaving the western part of the fold free to slide over the eastern one (IV). At this point in the process, then, there were two series of rocks, one above the other, with the sequence of strata exactly repeated. However, during the very slow movement of the overriding block toward the east, the front of it was continually breaking down and being eroded away, so that at no time was there such an overhanging mass as appears in IV of the theoretical diagram. Moreover, the younger softer rocks of the overriding block were also worn away, etching out the limestones beneath into the present irregular mountain summits. And in addition, the younger rocks of the lower series were likewise eaten away by erosion, not only in front of the uplifted mass, but also where they actually underlay its limestones (V), thus undermining the latter until

they broke off in huge blocks and left those tremendous vertical faces with which many of the Park's mountains confront the rising sun.

All of these phenomena, from fissures to faults, are manifestations of the fact that the earth, even with its immensely long history, has not yet reached a state of peace, but is still in travail. The broad movements of the outer surface are slow indeed—far too slow for us to see—but when we add together the bits of testimony from many places it becomes clear that the lands warp into low domes and hollows, or are bowed up into long and wide arches, some of which are more than a thousand miles across. Such areas are the Rocky Mountains and the Andes, which have been arched and elevated, subsequent to their being folded, to heights of a mile or two and with the length of a continent. Geologists also know that the oceans have flooded vast areas of the lands; in fact, strata that have been formed beneath sea-level are now found in the mountains at elevations of 29,000 feet. Remarkable as it may seem, it is nevertheless true that formerly dry lands have, in geosynclinal areas, gradually gone down to 40,000 feet and even more below sea-level, and then have been pushed up into mountains as high as the Himalayas. Because of all this adjustment, strains and stresses are being continually increased in the crust until the maximum strength of the rocks has been reached, and then they must either tear apart, fold, or thrust over one another.

Although the earth's shell is thus periodically in very slow motion, this goes on as a rule a little at a time, and now here and now there, so that we do not often perceive the movements. Occasionally, however, the crustal ad-

AN OVERTHRUST REMNANT

Chief Mountain, Glacier National Park, remains of a mass of ancient limestones shoved by thrust faulting a distance of 15 miles. The softer rocks on which the mountain rests (below timber line) are much younger (Mesozoic). Photograph by the U. S. Geological Survey.

justment occurs suddenly, and then we have earthquakes, which seem to give the lie to our idea of the "solid earth." The study of earthquakes long ago of necessity became a scientific one, and instruments have been invented to detect and record the earth's smallest tremors. Certain of these recording instruments are called seismographs, from the Greek word *seismos* meaning earthquake, and their automatically made records are seismograms; still more sensitive ones, known as seismometers, record the preliminary microtremors—the "microscopic earthquakes." When enough of these machines are set up and their records studied, geologists will be able to predict the coming of earthquakes.

When an earthquake takes place, the shock sets up waves which, when they travel long distances around and through the earth, arrive at any seismograph in sequence. One set, the smaller or preliminary tremors, take the shortest route through the earth, i.e., along a chord from the seat of disturbance direct to the recording machine; while the other waves of the main shock travel much farther because they go along the surface of the earth, and hence arrive later. This fact makes it possible to work out a rule for determining the location of the earthquake center, which is as follows: the duration of the first preliminary tremors in minutes (and fractions of minutes), less one, is the distance of the place of disturbance in thousands of kilometers.

An earthquake is a trembling, shaking, or undulating motion of the earth's surface, caused in the great majority of cases by a sudden dislocation in the crust along a new or old line of fracture, the suddenness of the displacement giving rise to a shock which is transmitted through

the earth. In a severe earthquake, the first phase consists usually of slight tremblings, or a series of separate shocks that last a few seconds. Then follows a violent motion, accompanied by rumbling sounds, and the earth actually rises and falls some inches, due to waves that rush about two miles per second, or shakes back and forth horizontally. The violent motion generally lasts but a fraction of a minute.

Earthquakes occur everywhere on land and in the ocean basins as well. They occur in great numbers, but for the most part are so faint that they are not felt and do no damage to man's works. Even so, nearly all lands sooner or later experience damaging shocks, but the severe ones take place mostly in what are called seismic belts, or regions subject to marked crustal displacements. Japan is the land of most frequent earthquakes, averaging about three of them each day as recorded on the seismographs. The Dutch East Indies is another region with frequent earthquakes, and still another is India, where the one of Kangra was felt through an area of 1,625,000 square miles.

Kipling, while in Tokio in 1892, experienced an earthquake that lasted two minutes. He writes of it as follows:

"Into the stillness of a hot, stuffy morning came an unpleasant noise as of batteries of artillery charging up all the roads together, and at least one bewildered sleeper waking saw his empty boots where they 'sat and played toccatas stately at the clavicord.' It was the washstand really, but the effect was awful. Then a clock fell and a wall cracked, and heavy hands caught the house by the roofpole and shook it furiously."

To humanity, the most destructive earthquake of modern times was that which took place in the area of Tokio and Yokohama on September 1, 1923. Following the first violent shocks, there occurred during the first four days in September, respectively, 365, 289, 173, and 143 "after shocks," and during September and October 1350 more followed. The first great shocks and the subsequent fire killed 106,032 persons and injured 32,583 more. Of houses there were destroyed 316,087. The cause of the earthquake seems to have been crustal movement in the sea to the east of Yokohama. In places the land rose 8 feet, while in the deeper waters of the bay the bottom has sunk 300 feet. This region had not, however, been stricken by a great earthquake since November 22, 1703.

Earthquake waves undoubtedly help to joint the rocks, and especially so in the immediate region of the crustal movement. It is in mountain regions, however, that they do their most tremendous work, causing landslides and shaking into motion avalanches of snow and ice. How great rock piles or talus heaps at the foot of cliffs may result from an earthquake is dramatically told by John Muir, who witnessed a severe earthquake in the Yosemite. He says:

> Among the most interesting and influential of the secondary features of cañon scenery are the great avalanche taluses, that lean against the walls at intervals of a mile or two. In the middle Yosemite region they are usually from three to five hundred feet high, and are made up of huge, angular, well-preserved, unshifting boulders. . . . Some of the largest of the boulders are forty or fifty feet cube . . . and where the cleav-

age joints of the granite are exceptionally wide apart a few blocks may be found nearly a hundred feet in diameter.

Almost every talus had been formed suddenly, in a single avalanche, and had not been increased in size during the last three or four centuries; for trees three or four hundred years old were growing on them. . . . All the taluses throughout the range seemed, by the trees and lichens growing on them, to be of the same age. All the phenomena pointed straight to a grand ancient earthquake. But I left the question open for years. . . .

One morning about two o'clock, I was aroused by an earthquake, and though I had never before enjoyed a storm of this sort, the strange, wild thrilling motion and rumbling could not be mistaken, and I ran out of my cabin, near the Sentinel Rock, both glad and frightened, shouting "A noble earthquake!" feeling sure I was going to learn something. The shocks were so violent and varied, and succeeded one another so closely, one had to balance in walking as if on the deck of a ship among the waves. . . . It was a calm moonlight night, and no sound was heard for the first minute or two save a low muffled underground rumbling and a slight rustling of the agitated trees, as if, in wrestling with the mountains, nature were holding her breath. Then, suddenly, out of the strange silence and strange motion there came a tremendous roar. The Eagle Rock, a short distance up the valley, had given way, and I saw it falling in thousands of the great boulders I had been studying so long, pouring to the valley floor in a free curve luminous from friction, making a terribly sublime and beautiful spectacle,—an arc of fire fifteen hundred feet span, as true in form and as steady as a rainbow, in the midst of the stupendous roaring rock storm.

ALESNA (THE BODKIN), A VOLCANIC NECK IN NEW MEXICO

CHAPTER XVII

THE UPWELLING OF THE FIRE ROCKS: VOLCANIC ERUPTIONS AND LAVA FLOWS

THE relative importance of the rôles played by water and by fire in the rock history of the earth was one of the great subjects for debate when geology was young. Benjamin Silliman, studying at the University of Edinburgh in the early years of the last century, found the geologists there divided into two strongly opposed camps: the advocates of fire, disciples of James Hutton (himself a Scot), known as Plutonists from Pluto, the god of fire; and the Neptunists, followers of Abraham Gottlob Werner, professor in the mining school at Freiberg, Germany. "Being a young man, uncommitted to either theory," says our great scientist in his journal, "I was a deeply interested listener to the discussion of both the Wernerian and Huttonian hypothesis. From the fierce central heat of the philosophers of fire, and its destructive

heavings and irruptions and overflows, I went to bathe in the cool ocean of Werner."

With the growth of geologic knowledge, this question has ceased to be agitated, and we think of water nowadays mainly in connection with its destructive work on the surficial rocks and its constructive building up of the stratified ones of the earth's crust, while the internal heat of the earth acts upon those at greater depths, where it works hand in hand with another powerful agency, pressure. Where this heat of the earth's interior comes from is beyond our ken, and it is not necessary here to cite the theories regarding it. All our evidence tends to show, however, that there is sufficient heat at these great depths, where the rocks are necessarily under immense pressure, to change them from a solid to a liquid or molten state the moment the pressure is locally relieved.

Once molten and seething with gases, this liquid rock mass, held in place by the pressure of the firm and cold crust, seeks a way of escape, and finds it when the solid rocks above yield to strains and stresses brought to bear upon them during times of crustal disturbance, as, for instance, when portions of the crust are being crushed together and pushed up into mountains. Such readjustments in the crust, as we have seen, pull the rocks apart, leaving cracks and fissures of all sizes and often of great depth, and these offer the restless magmas a pathway of escape which they are quick to embrace. Driven by the expansion of their own gases, and by hydrostatic pressure as well, they start upward in these channels. When no serious obstacles intervene, they rise through the miles of crust, and, if they are surcharged with gases and steam, burst out at the surface with explosive fury, throwing

high into the air rock fragments and rock dust or ash, some of which falls back again about the vent and so builds the familiar volcanic cone. When the amount of gas and steam is less, the molten rock flows out quietly over the surface as lava. If, on the other hand, access to the surface is prevented by some impassable rock barrier, the magmas solidify in their fissures or in great caverns made by their own forces, or squeeze their way sidewise between the stratified layers of rock and spread out as relatively thin sheets. Since, however, volcanic eruptions are the most striking of these phenomena, we may turn our attention to them first, leaving for later discussion the less well-known manifestations.

Ranking alongside of earthquakes in their destructiveness to man are the great volcanic eruptions that have written lurid pages into his local history. Sometimes the two have occurred in conjunction, but either alone was sufficiently terrible to cause the ancients to ascribe to it a supernatural origin. The very word volcano, first applied to Mt. Etna, comes from Vulcan, the Roman god of fire. Six hundred years before Christ, a Roman, asked what Etna represented, would unhesitatingly have replied that Vulcan's smithy, in which he forges thunderbolts for Jove, lies underneath the mountain, and that Etna is the chimney of his forge.

The ascription of supernatural powers to mountains and volcanoes is, moreover, by no means lost in modern times. Fujiyama, the most gracefully symmetrical of all the mountains of fire, is still to the sons of Nippon the "holy mountain," and each year in the month of August thousands of Buddhist pilgrims ascend it. Purchasing at the shrines prayerful *goheis* floating from sticks, they

thrust them into the crevices of the rock as they climb. At sunrise the devotees at the top, kneeling with their heads covered by a white cloth, adore the sun and in deep tones chant litanies. Then, going clockwise around the crater, they pass many small shrines, and repeat in chorus *"Rokkonshojo,"* which expresses the purity of flesh and spirit.

Volcanoes may stand alone, as do Vesuvius near Naples and Etna in Sicily, or in crowds as in the Auvergne region of France and the country to the west of Naples. As a rule they are aligned or dispersed over long and narrow zones. Those known to have been active in historic times number about five hundred, but there are probably ten times as many that have not been long extinct. The greatest number of them occur around the shores of the Pacific and of the greater mediterranean known as Tethys which extended the Roman mediterranean across Asia to India and thence to Burma, Siam, and the Dutch East Indies. Some countries have now no volcanic cones at all, as Scandinavia, Siberia, and Australia, but it is probable that few parts of the earth have been without them throughout the course of geologic times. The only live volcano now left in the United States is Lassen Peak, in California, and its activity is very feeble. In earlier ages, however, Mounts Hood, Adams, and Baker, Mount Rainier, the White Peak of the Indians, and Shasta, that "pole-star of the landscape," were all parts of the circle of fire that girdled the Pacific.

Volcanoes are by no means restricted to the lands, but are common in all the oceans where cones and volcanic ridges have grown up from the bottom. The small group of British islands, the Bermudas, are of this nature. At

RAINIER, ONCE A FIRE MOUNTAIN, NOW MOTHER OF GLACIERS

In past geologic ages, Mt. Rainier was one of the great volcanoes that girdled the Pacific with a chain of fire. Before it was beheaded by an eruption, the summit towered half a mile higher. Photograph by Curtis, reproduced by permission of the Great Northern Railway.

the surface they are all of limestone, largely made of corals, and but few people suspected their volcanic origin until the Princess Hotel, in attempting to sink a well, struck decomposed lavas at a depth of 360 feet. The Bermudas are therefore perched on top of a long extinct volcano whose summit at one time was submerged at least 360 feet beneath the surface of the ocean. In the Pacific there are many volcanoes now covered with very thick coral reefs.

The majority of places having volcanoes and erupted rocks, either of recent or ancient origin, are connected with faulted and down-broken regions. These are the zones of weakness in the earth's crust. It is easy, therefore, to see why the great eruptive activities of our time occur along the borders of the Pacific, which is the greatest sinking field of the earth, or along the shore of Tethys. We must not, however, conclude from this that it is the faulting alone which causes the eruptions; all that is certain is that these deep fissures are the channels through which the magmas rise to the surface.

From a study of the immensely long geologic record preserved on the continents, it appears that volcanic activity is most often connected with mountain making, either through folding of the earth's crust or through the down-breaking of highly elevated plateaus. With gentle warpings of the crust there is apparently no such marked activity. The volcanoes may appear during the earliest stages of these periodically recurring times of crustal unrest, but they are most active during the time of greatest mountain making, and then they gradually die down with the ceasing crustal movements. At other times, however, immense volcanic activity occurs when

no mountains or plateaus appear to be rising, since in Triassic times thick deposits of lavas and ashes were accumulated all the way from California into Alaska. These are interbedded with marine strata and therefore the volcanoes must have stood in the sea, and in a decidedly subsiding sea (geosyncline), since the accumulations are very thick. We have also seen that volcanoes are scattered over all the ocean bottoms. The inference therefore is that volcanic activity frequently accompanies marked subsidence.

Volcanoes are typically conical in form, because they have literally built themselves up through the pouring out of rock materials. This comes up from deep within the earth through conduits called vents, which terminate in openings known as craters. There may be one crater at the top or on one side, but commonly there are several, and occasionally even hundreds. Through the extrusion of materials, volcanoes on the lands have grown from sea-level to heights of over 12,000 feet, and others have grown to similar altitudes from the tops of greatly raised plateaus like that of the Andes, which lies 14,000 feet above the sea; on the border between Chile and Argentina, for instance, stand Tupungato (21,500 feet) and Aconcagua (23,000 feet). In Ecuador some of the high volcanoes are still active, as Cotopaxi (19,600 feet) and Chimborazo (20,500 feet).

A volcano may be continuously active for a day, or several days, or months and even years, but sooner or later all of them become quiet. The solid materials that build up the cones may be thrown out gently, or with extreme violence. When there is little vapor and gas, the melts of rock rise gently and flow out as lavas, but

VOLCANIC "CAULIFLOWER CLOUDS"

The volcanic cloud over Mt. Sakuraschima, in southwestern Japan, during its violent eruption of January, 1914. Courtesy of *The World's Work.*

when gases have been pent up with the magmas, the rock is blown apart and thrown out violently in large and small fragments. Bombs are fragments larger than apples and ranging up to several hundred pounds in weight, lapilli are those the size of nuts, while the smaller material, coarse to fine rock dust, is commonly called ash.

During the explosive eruptions, the clouds of rock dust and gases above the craters are accompanied by striking electrical displays, the lightning being generated by the friction of the ejected materials. In the great "cauliflower clouds" there is an immense amount of water-vapor or steam, and one of the subsidiary cones on Etna is estimated to have discharged each day while in action about 4,600,000 gallons of water. This steam soon expands and cools, giving rise to heavy rains that wash down the fine dust of the clouds and of the land and so give rise to widespread mud flows, which are often more devastating than the floods of lava. The thick lavas, as a rule, flow very slowly, but the thin liquid ones on steep slopes may rush along at 10 miles per hour, and some of them have traveled a distance of 45 miles.

On the basis of the strength of eruption, volcanoes are grouped into three categories: (1) quiet, those that erupt lavas only; (2) violent or explosive, those from which shoot the bombs and clouds of ashes; and (3) intermediate, the common type that sometimes expels lavas quietly and at other times blows out ashes with violent force. A brief survey of some of the better known ones will best illustrate these three types.

The greatest of active caldrons (craters) are those of the Hawaiian Islands. These islands in the middle of the Pacific Ocean are at the eastern end of a submerged ridge

that is 1000 miles long, trending northwest, and all of which is thought to have been built up by submarine lavas that flowed out over the ocean bottom, raising the ridge 16,000 feet to sea-level. On the island of Hawaii are the peaks of Mauna Kea (13,085 feet), Mauna Hualalai

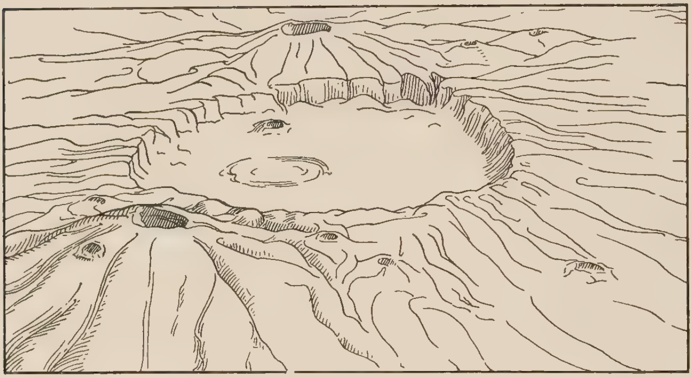
A LAVA STREAM

Molten lava descending the slope of Mauna Loa, Hawaii, with the fated village of Hoopuloa in its path. Photograph by the U. S. Army Air Service, April 18, 1926.

(8300 feet), and Mauna Loa (13,675 feet); the first of these is extinct, the second was active in 1801, and the third is active now. Kilauea, the great crater pit of Mauna Loa, 20 miles from its summit down the eastern slope, is a rudely oval caldron about 9 miles in circumference. Its floor of lava is in the main cold and solid,

resting on a column of molten rock below. In 1885 there issued out of Kilauea a lava stream from 3 to 10 miles wide and on the average 100 feet thick, which ran down the mountain for 45 miles. The caldron boils in places with red to white-hot lavas that are scattered about by the issuing gases.

The greatest known craters, now extinct, occur in the heart of eastern Africa. Here are some of the largest



NGORO CRATER, AFRICA

Largest of all known volcanic caldrons, 12 miles across and 2,000 feet deep. From a model made by James L. Clark for the American Museum of Natural History.

volcanoes, chief among them being Kilimanjaro (19,456 feet), whose top is always covered with snow despite the fact that it lies but a few degrees south of the equator. This is, indeed, one of the greatest volcanic regions of the world, an area several hundred miles across from west to east and about 2000 miles long from Abyssinia south to Lake Nyassa. In general it is now inactive. Not far away from Kilimanjaro are the "Highlands of

the Great Craters," and the crown of these is Ngoro, the largest known caldron. This pit, according to James L. Clark of the American Museum of Natural History, who visited it a few years ago, is circular in outline, its floor 2000 feet beneath the rim and 12 miles across. "What a fire pot it must have been!" On the rim are perched good-sized volcanoes, Olomoti and Oldeani, which rise 2000 feet higher. The lava plain walled in by the crater rim is abundantly covered with sweet grass, while the steep-sided rim itself has a dense forest and many springs of cool water. This now peaceful caldron, with its hot days and cool nights, maintains the largest and most interesting natural zoölogical park known; it is replete with birds, and there are estimated to be about fifty thousand antelopes, gazelles, zebras, buffaloes, rhinos, and elephants, on which are feeding lions, hyenas, and jackals.

The most explosive of volcanoes is Krakatoa, a small island in Sunda Strait near Java. It has an area of 12 square miles and the highest point stood 2800 feet above the sea. It had been quiet for about two hundred years, and then in the night of August 26-27, 1883, after some warning outrushes of gas, almost the whole of the island top blew into the air, sending up about 13 cubic miles of rock and a cubic mile of fine dust that finally attained the remarkable elevation of between 20 and 40 miles. Bombs were thrown around for 12 miles and lapilli for 25 miles. The new crater became a sea over 900 feet deep, and the explosions were heard more than 150 miles away. Waves reaching a height of 100 feet were generated in the sea by the eruption and these rushed upon the lowlands of Java and Sumatra, killing between 30,000

and 40,000 people. Some of the fine dust circulated several times around the earth and was three years in settling back to the surface, causing at the time remarkably red sunsets.

Etna stands beside the sea in Sicily, and since the time of Christ has been in eruptive action about eighty times. It is the highest volcano in Europe. Its lower gentler slopes are replete with parasitic cones, of which there are more than two hundred, some of them 700 feet high. Even though Etna is called a burning mountain, this fire is not due to internal combustion of materials like coal or petroleum, as was long believed.

Of the intermediate volcanoes, those which have eruptions of both the quiet and explosive types, Vesuvius, about 9 miles southeast of Naples, is one of the best examples and is, in fact, the best-known of all volcanoes. The present Vesuvius occupies the site of an older one, which in the time of the Romans appeared to be extinct, for although they recognized its nature they had no traditions of its having been active. In the year 79 A.D., however, the volcano erupted violently and destroyed the towns of Herculaneum and Pompeii on its seaward flanks, burying them beneath mud flows, pumice, lapilli, and ash. A great part of the former crater, on the side toward the sea, was blown away, or engulfed, and in its place the new center of activity, the modern Vesuvius, began to build up. This has periodically continued until now the new cone is about 4200 feet high. Partly enclosing it lies the crescentic ridge of Monte Somma (3730 feet), the remains of the older crater. The volcano is in a state of almost constant, relatively mild activity with irregular periods of violent eruption.

Vesuvius was in violent action in 1906, destroying nearly 200,000 acres of vineyards, farms, and forests, deluging them with ashes, lapilli, and bombs. W. P. Andrews wrote a vivid description of this eruption for the *Century Magazine*, a part of which reads as follows:

> The spectacle from all around the Bay of Naples was not only tremendous and awe-inspiring, but also gorgeous to the last degree. The pall of smoke was swept aside for an hour or two, about four o'clock in the morning, and the glowing lava stream, the fiery crater, and the burning woods and houses lighted up the wide expanse of waters till the whole great gulf looked like an enormous sheet of fire. Above, the stupendous pall spread itself forth, vividly illuminated by jagged lightnings; but the smoke closed in again, and for a week nothing was seen of the region round the mountain. On Sunday noon, above this impenetrable mist rose a billowy column of copper colored cloud, which reached an inconceivable height, variously estimated, according to the standpoint of the observer, at from two to five miles. At the top, this ruddy cloud spread itself out like an enormous stone pine, till its branches seemed to overshadow the whole country round the bays. The brilliant April sunshine turned to a pale glow, like the weird light that accompanies the total eclipse of the sun, and this effect lasted for days. Early Monday morning, even at Capri, twenty miles away, it was impossible to see one's hand before the face.

Long after a volcano ceases to be active the land about will emit gases, chiefly carbon dioxide, and hot water. The "Land of Ten Thousand Smokes" in Alaska near the periodically active Katmai is one of these places, with its many openings through the ground to the hot rocks below, from which rise hot sulphur fumes and other gases. These openings have long been known as fumaroles, from the Latin word for smoke.

Volcanic activity affects the climate locally by the great emission of heat and steam, and widely by the addition to the atmosphere of carbon dioxide and dust. Explosive volcanoes will shoot high into the atmosphere immense amounts of dust; Krakatoa, for example, in 1883 threw out into the air about one cubic mile of fine dust. It takes years for this dust to fall back upon the earth, and while it is afloat it screens out the sunlight and brings on cooler weather. Therefore it is believed that during ancient times of great volcanic activity there may have been so much dust in the higher atmosphere as to reduce by some degrees the mean temperature of the earth. Hence volcanic dust is a contributing cause toward colder climates, while carbon dioxide to a slight extent helps to warm the air. On the other hand, if volcanoes should cease to be active in the future, seemingly there would come a time when no land plants could live for want of the food they find in the carbon dioxide of the air, and hence there could be no land animals and no human beings, not only because of the lack of food but because free oxygen would be lacking as well. And if there had never been volcanoes and internal earth heat, there would have been neither atmosphere nor oceans nor rains.

Many of the dead volcanoes still retain their original conical form and are familiar features of our landscapes. It sometimes happens, however, that the materials of which the outer part of the cone was built are worn away after the activity has ceased, leaving behind to mark its former presence only the harder solidified core of igneous rock, which is known as a volcanic neck. Mount Royal, near Montreal, is such a volcanic remnant, and still finer examples are to be seen in Arizona, New Mexico, Cali-

BULKLEY GATE, BULKLEY RIVER CANYON, BRITISH COLUMBIA

A cut made by the river through a dike or vertical wall of volcanic rock. Reproduced by courtesy of the Canadian National Railways.

fornia, and other western states. In South Africa the volcanic cores have an added interest as the homes of the great diamond mines, the gems being included in the volcanic rock known as "blue ground."

In addition to the lava poured forth by volcanoes, tremendous floods of it have flowed out through fissures. Such floods make wide plateaus, since sheet upon sheet of lava is piled up until the depth reaches thousands of feet. In the United States, a good example is the vast basalt plateau of the Columbia and Snake rivers in Idaho, Washington, and Oregon, with an area of about 200,000 square miles, in which the sheets reach thicknesses of 3000 feet. The greatest of all lava floodings, however, took place in Peninsular India, where the Deccan traps, originally spread over half a million square miles, still cover more than 200,000 square miles to a depth varying between 2000 and 10,000 feet.

Volcanic eruptions and lava flows at the surface are extrusive in nature, but the liquid rocks that fail to reach the surface, the intrusives, are probably even greater in amount, although they are visible to us now only when the rocks around or above them have been worn away. It is not uncommon to see strata at the surface cut through by a vertical band of darker rocks that were formed by the solidification of magma. These so-called dikes may be a few inches wide, or several hundred feet; in length they range to 100 miles, though an extent of 5 to 20 miles is more usual. When the rocks on either side of the dike have disappeared, it may stand up like a vertical wall.

The Palisades of the Hudson River represent a great lava intrusion that spread laterally between sedimentary

rocks far below the surface, and is now exposed because the strata formerly above it have undergone complete erosion. Of like origin are the trap ridges so conspicuous in New Jersey, Connecticut, and Nova Scotia, so called from the step-like (German *Treppen,* steps) appearance that the rocks often present. When these underground masses of lava dome up the overlying strata, we call them laccoliths, or cistern rocks.

Greatest of all the masses of magma that have solidified beneath the surface are the batholiths ("depth rocks"). Along the Pacific coast these igneous masses, now exposed by erosion, stretch from Lower California to the northern California border and from northwestern Washington into the Alaskan Peninsula in a three-thousand-mile chain; that of the Sierra Nevada is 400 miles long and has a maximum width of 80 miles; on the International Boundary twelve of them have a combined width of 350 miles; and the mighty Coast Range batholith, probably the greatest single intrusive igneous mass known, with a width varying between 30 and 120 miles, extends unbroken for 1100 miles into the southern Yukon. In comparison with these tremendous upwellings of fire rocks, most other igneous phenomena fade into insignificance.

Photograph by Walcott.

TERRACES OF MAMMOTH HOT SPRINGS, YELLOWSTONE PARK

CHAPTER XVIII

NATURAL HOT-WATER FOUNTAINS: GEYSERS AND HOT SPRINGS

MOST of the processes comprehended under the term "geologic" are so slow moving that we see their results only in the aggregate. There is, however, one class of phenomena which, though they may be but end-results of a long accumulation of effects, by their suddenness and violence register themselves decidedly on the consciousness of mankind. These are the so-called igneous phenomena, that is, those connected in some way with the heat stored up in the rocks. Most conspicuous and widely-known of these are the volcanic eruptions which have previously been discussed, but hardly less marvelous to the beholder, though lacking the destructiveness of the volcanoes, are those natural hot-water fountains, the geysers, which occur in a few widely scat-

RIVERSIDE GEYSER, YELLOWSTONE NATIONAL PARK

Although not one of the greatest geysers, Riverside throws water and steam to a height of 100 feet. It takes on added interest from its location beside the cold waters of the Firehole River. Photograph by Walcott.

tered parts of the earth. Discovered in Iceland, and studied there by Bunsen and Descloizeaux as early as 1847, they find their best development in our own American geyser field, in Yellowstone National Park, which

was first seen by a trapper, John Colter, in 1807, and pictured by him in such lurid terms as to be known for years afterward by the suggestive name of "Colter's Hell," but not thoroughly explored and described until almost sixty years later. A third such region, discovered some sixty years ago, exists in New Zealand.

The explosiveness of the volcano is simulated in many geysers, but the matter expelled by the latter is, as a rule, steam and hot water, which is thrown into the air sometimes to distances of several hundred feet. These eruptions are irregular in occurrence, varying with each geyser, but generally regular enough, even in their irregularity, to be charted in "time-tables." Some geysers erupt once a year, others every five minutes; in some the activity gradually ceases, just as volcanoes become extinct, but new ones are constantly breaking out. The most familiar of them all is Old Faithful, which sends its column of water and steam from 125 to 150 feet into the air about every seventy minutes, day and night, summer and winter, and has been doing so ever since its discovery in 1870. Standing somewhat alone, on a slight elevation built up by the deposits of its own waters, this most admired of geysers presages its master effort by sending up jets of steam and water 15 to 20 feet above its bowl. These die down, only to rise higher with each recurrence, until finally a superb column of white water sweeps mightily upward to stand silhouetted against the dark forests and the azure sky.

The first sight of a geyser field leaves no doubt in the observer's mind that heat is the keynote of its activity. The whole earth is a-steam, curling up lazily like smoke, blowing off from the surface of hot pools, bubbling up in

"mud pots," and being shot into the air with violence. The sense of underground forces, restless and threatening, is everywhere impossible to escape. Such fields occur usually along the banks of rivers or in regions where there would naturally be fissures in the earth's crust. Yellow-

ONE OF THE GEYSER BASINS THAT GAVE TO THE YELLOWSTONE REGION THE NAME OF "COLTER'S HELL"

stone has within its area three of these geyser basins, one of which contains twenty-six geysers and more than four hundred hot springs.

Assuming that the three geyser fields of the world have been similar in origin, that of Yellowstone, which has been studied exhaustively by Government geologists, may be taken as the type. The question that leaps to the mind, after the first shock of astonishment has ebbed,

is, naturally: What is the cause of these geysers? The answer lies, first, in the geologic history of the Park itself. It is a vast area built up of lava poured out by volcanoes on its borders, all of which are now extinct. Not, probably, by explosive eruptions, but by steady outpourings of molten rocks from these vents, the country around was built up into a lava plain which now stands at an average level of 8000 feet above the sea. And the significant thing here is that this occurred not many years ago, geologically speaking, so that the heated lavas have not yet had time to cool to great depths below the surface. We have, then, below the present flooring of the Park, a great mass of still hot igneous rocks, ready to act upon anything with which they come into contact.

The second significant thing about the igneous rocks flooring the Park is that they belong to the acidic group of volcanics, which are much more susceptible to the dissolving action of hot waters and vapors than are those of the basic type. The steam from the hot lavas below, therefore, eats its way through them with comparative ease, opening channels for the descending surface waters, which, coming in contact with the hot rocks, are heated to the boiling point and thus are returned to the surface as hot springs or geysers. The springs occur in all stages from actively boiling caldrons to still pools of warm water, or they may contain particles of disintegrated rock and so become boiling "mud pots," sometimes called "paint pots" when colored by various oxides.

The explosive action of the geysers, however, needs still further explanation, and no better one has been offered than that conceived by Bunsen after his study of the Icelandic field. His idea was that some of the fissures in

the rocks widen out sufficiently to form an underground chamber or tube, which fills with water and thus brings it in contact with the hot lavas below, just as a test tube may be heated over a flame. The boiling point of water, as is well known, is raised under pressure, hence the water at the bottom of the geyser tube is slower in reaching the boiling point than that in the upper part. When the water toward the top of the tube boils, however, it spills over, and thus lessens the pressure on the lower levels of the water, which then flies into steam and is ejected violently. The regularity of geyser eruptions results, and the varying schedules of eruption in the different geysers depend upon the length of time it takes the tube to refill with water and bring it to the boiling point.

The water thrown out by the geysers, as it falls back, generally deposits white siliceous sinter, or geyserite, around the vents, and this in time is built up into varying shapes, which give to the geysers such names as the Beehive, the Castle, the Sponge. This same rock, where it has been made into immense terraces by hot springs, often takes on marvelous coloring from microscopic plants (algæ) ranging through all the shades of pink to warm yellows and oranges and browns, for, strange as it may seem, these low types of plant life thrive and procreate in hot waters. Even this coloration, however, is surpassed by that in certain of the pools, which seem to hold in their depths water of vivid hues of emerald and turquoise such as one sees elsewhere only in the heart of rare and precious gems.

Warm springs may also occur in regions that show no trace of volcanic activity, as at Hot Springs, Virginia. These originate when the surface waters go down to a

depth of, say, a mile or more, and come into contact with rocks that have become heated because of chemical changes within themselves, or because of crustal movements, or simply because, as observations show, the earth's temperature rises about one degree Fahrenheit for every 65 feet of depth; consequently, when they are forced back to the surface through fissures, they issue as warm springs. Such warm waters also readily take up substances in solution and in this way give us the mineral springs whose medicinal qualities are recognized the world over. When these springs contain carbon dioxide in quantity, they deposit around their orifices a calcium carbonate rock called travertine, of which onyx is a well-known variety.

Photograph by Harmon, courtesy of American Geographical Society.

MT. ROBSON, MONARCH OF THE CANADIAN ROCKIES

CHAPTER XIX

MOUNTAINS, THE BEGINNING AND END OF ALL SCENERY

> Stainless ramps . . .
> Ranged in white ranks against the blue—untrod,
> Infinite, wonderful—whose uplands vast
> And lifted universe of crest and crag,
> Shoulder and shelf, green slope and icy horn,
> Led climbing thought higher and higher, until
> It seemed to stand in heaven and speak with gods.

TO early man, with his simple needs of food and shelter, the mountains must have been fearsome things. The floods that sweep down their valleys, the great avalanches that come rushing down to destroy him and his dwellings, the mysteries of clouds, thunder and lightning, and glaciers: all these led him, naturally enough, to people the mountain regions with the gods whom he could not see but of whose power he had such frequent manifestations. Traces of this feeling still per-

sist in many peoples, as travelers often testify. Asia, the supposed cradle of man, has more and higher mountains than any other part of the globe, and to them have gone since time immemorial priest and pilgrim for inspiration and forgiveness of sin. Even now the Hindus write their prayers on banners fastened to poles so that the winds may waft their praises and supplications up to the regions of the gods, far, far beyond the crests of the mountains, to bring down upon themselves blessings and good fortune.

Love for the mountains probably did not develop until man's struggle with his environment became less severe, leaving him more leisure to look about him and speculate on what he saw. When he first conceived the idea of climbing them we of course do not know, but as early as the first century of the present era the Roman emperor Trajan is said to have ascended Mt. Etna "to see the sun rise." Perhaps the first of the medieval scholars to climb a mountain for its own sake was the poet Petrarch, who made the ascent of Mont Ventoux in Provence in 1336, and found there such food for the soul that the following year he went to live at Vaucluse, where he could commune with nature in her wildest moods. The earliest systematic climbing of the Alps dates from the days of Konrad von Gesner (1516-1565) and Josiah Simler. Since those days mountaineering has constantly found a place in the hearts of mankind, and one by one the great peaks have been conquered and their mysteries explored. The summit of Mt. Everest, the highest of them all, is, however, still virgin, so far as is known, the two lost members of the exploring party of 1923 disappearing about a thousand feet below the crest.

North America is abundantly provided with mountains of various types, and these are rapidly being made accessible by our growing system of national parks. The Appalachians in the East, the oldest and the longest known,

PLOTT BALSAM MOUNTAINS, NORTH CAROLINA

A portion of the old, deeply dissected Appalachian Plateau. Note the even height of most of the mountains, their rounded summits, and the heavy timber that mantles them, as contrasted with the sharp-crested peaks of the younger and higher Rockies. Photograph by Keith, U. S. Geological Survey.

have no such great reserves as there are in the West, but small areas here and there are being set apart. This great system, stretching from Newfoundland almost to the Gulf of Mexico, owes its special geologic interest, as we have already seen, to the fact that it is but a remnant of a once higher system that has yielded its majesty to the

power of rain and wind. The loftiest of its peaks, Mt. Mitchell, scarcely tops 6700 feet, while Mt. Washington, its nearest New England rival, lacks 400 feet of this height.

Western North America is replete with lofty mountain systems extending from southern Mexico into extreme northwestern Alaska, about 4000 miles; these together are spoken of as the Cordillera. The greatest width of this mountain area, 1100 miles, is across Colorado and New Mexico to the Pacific coast, and it tapers each way to a breadth of about 400 miles. The Cordillera includes the Rocky Mountain system of the United States, Canada, and Alaska, the Sierra Madre of Mexico, and the Pacific system extending along the western margin of the continent from California through westernmost Canada into coastal Alaska. Between the Rockies and the Pacific Mountains lie much faulted and dissected plateaus, which, from south to north, are known as the Colorado Plateau, the Great Basin Province, the Columbia Plateau, and the Interior Plateau of Canada (see figure, page 125).

The great Rocky Mountain system finds its best representation in this country in the state of Colorado, which, with one-seventh of its area standing 10,000 feet above the sea, has 350 peaks above 11,000 feet, 220 above 12,000 feet, and 150 higher than 13,000 feet. Furthermore, of the 61 named mountains in the United States (exclusive of Alaska) that exceed 14,000 feet in altitude, Colorado has 47. On the Canadian side of the border, the Rockies are best known in the region around Banff, British Columbia. They are here traversed by the Canadian Pacific Railway, which enters them at Calgary and

runs west for 500 miles through "a continuous panorama of the grandest mountain views visible from a railroad track." The width of the Rockies proper averages here about 60 miles and between them and the Selkirk Range is the Rocky Mountain Trench, a wide depression with a remarkable length of 900 miles, not drained by a single great river, but occupied in turn by the headwaters of eight lesser streams. The highest peak in the Selkirks is Mt. Selwyn (11,038 feet), while the monarch of the Canadian Rockies is Mt. Robson (13,068). Sixty miles to the south stand Mt. Columbia (12,500) and Mt. Forbes (12,000), with their grand array of peaks and glaciers. James Outram, in his fascinating book, *In the Heart of the Canadian Rockies,* says that the most striking feature of the Canadian Cordillera is the glaciers, "scarcely a peak 10,000 feet in altitude being without at least one." The Canadian Rockies and the Selkirks between the 50th and 53rd parallels have, indeed, been styled the "Switzerland of the Western Hemisphere."

Western California has the Coast Range, the youngest mountains of the Pacific System, to the east of which is the Great California Valley, a sea-way in earlier geologic time. On the eastern border of the state are the Sierra Nevada, which extend northward through Oregon and Washington as the Cascades, while on the western border of Canada and southern Alaska lie other coast ranges, with a different geologic history from that of California. Into all of these mountains, after they had been folded, upwelled from great depths vast masses of igneous rocks, and in consequence here are some of the greatest granitic cores known to geologists. These molten rocks also brought up with them from the depths the gold of Cali-

fornia, and the gold, copper, lead, and zinc of western Canada. The Canadian Coast Mountains rise directly out of the Pacific to elevations ranging up to 6000 feet, and increase inland to between 8000 and 9000 feet. The fiords along the coast of British Columbia and Alaska and the many islands near the shore represent drowned river valleys and ridges, Vancouver and Queen Charlotte Islands being remnants of another parallel range now still more submerged. This "Insular Range" stands on the very edge of the continent.

The Yosemite National Park, in central eastern California, a region of high granite mountains centering around snow-capped Mt. Lyell, is unlike any other. The usual entrance is from the west through the "Gateway" into the beautiful Yosemite Valley, which has been carved out of the long western slope of the Sierra Nevada fault-block by the Merced River and its tributaries, and then further deepened and widened by the work of glaciers. Guarding the gateway on the left is El Capitan, rearing its head vertically for 3000 feet above the valley floor, and on the right are Cathedral Rocks. The bold outlines of these and other of the Yosemite mountains bear testimony to the enduring character of the granite of which they are composed; while water and ice and weathering have carved their more submissive companions into delicate spires and serrate crests, these granitic masses have stubbornly refused to yield; "El Capitan, more than any other cliff," says F. C. Matthes, chief of our Government topographers, "may be said to typify the Rock of Ages."

The Yosemite found its interpreter in John Muir, who says of the view from Mount Dana:

EL CAPITAN, GUARDING THE ENTRANCE TO YOSEMITE NATIONAL PARK

Composed of granite, it has maintained its bold front through millenniums of attack by wind and water, snow and frost.

You are now more than thirteen thousand feet above the sea, and to the north and south you behold a sublime wilderness of mountains in glorious array, their snowy summits towering together in crowded, bewildering abundance, shoulder to shoulder, peak beyond peak. To the east lies the Great Basin, barren-looking and silent, apparently a land of pure desolation, rich only in beautiful light. . . . Westward you look down and over the countless moraines, glacier meadows, and grand sea of domes and rock waves of the upper Tuolumne Cañon, and across the dark belt of silver firs to the pale mountains of the coast. . . .

The main cañons are from fifty to seventy miles long, and from two to four thousand feet deep, carved in the solid flank of the range. Though rough in some places and hard to travel, they are the most delightful of roads, leading through the grandest scenery, full of life and motion, and offering most telling lessons in earth sculpture.

As the mountains in the various parts of the globe came to be explored, the data brought back went to the building up of a mass of growing knowledge as to the shape and size of the individual mountains, their grouping together into ranges or even greater systems, and the constant wear upon them by atmospheric agencies. Of their internal structure, however, and their origin, nothing was known until the close of the eighteenth century, when geologists, first in one country and then in another, began to speculate upon how these conspicuous features of the landscape came to be. This question is a far more difficult one than that of their destruction, since we cannot, obviously, witness the growth of a mountain, whereas the method of its wearing down is exemplified on a small scale in every mountain torrent. It is, indeed, only after a century of patient detailed study of the rocks making up

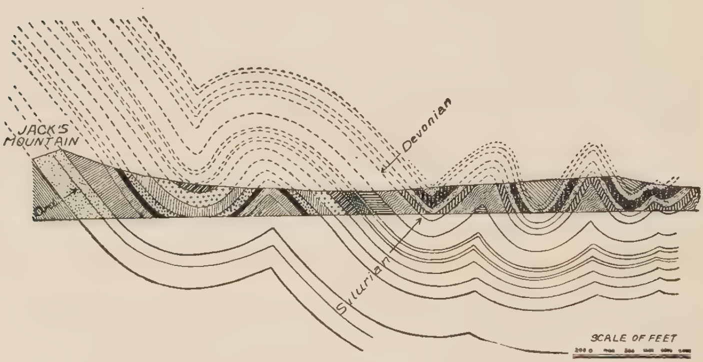
the many mountain regions of the world that our present notion as to how and why mountains are made is reaching stability.

The most striking thing that has developed out of the geologic work in mountain regions is that mountains have not all come about by the same process, but are of various types, however similar they may be in outward appearance. At the bottom of their creation we find, as we should expect, the same factor of crustal movement that is responsible for most of the changes which the earth undergoes, and this crustal movement has for its probable ultimate cause the shrinkage of our periodically cooling earth. Given, then, a crust in movement, how do mountains result?

To the layman, mountains are merely conspicuous surficial features with limited summit areas, but the geologist sees in their elevations, or, when they are worn down, in their roots, the crumpled and broken—folded and faulted—areas of the earth's rigid crust, which buckles upward in order to adjust itself to the shrinking interior mass. By far the commonest type of mountains are those in which the earth's crust has been folded into arches (anticlines, in geologic parlance) and hollows (synclines) through pressure from lateral or horizontal forces, just as a sheet of paper will wrinkle if the two sides are pushed toward each other. These are the "backbones of the earth," the more characteristic mountains—fold-mountains—of the geologist, including, as they do, most of the great systems: the Alps, the Himalayas, the Andes, and the Rockies. The wrinkling, however, varies greatly in intensity, and as some mountain systems have been folded more than once, it follows that

the original simple folds may become much accentuated, or even compressed, and are often further complicated by faulting and thrusting.

The simplest of these so-called fold-mountains are the Juras, which stand between France and Switzerland. Here the strata are in such open folds (anticlines and synclines) that the Juras have been spoken of as fluted



THE INTERNAL STRUCTURE OF FOLD-MOUNTAINS

Appalachians, near Lewiston, Pennsylvania. The dotted lines indicate the portion worn away, the upward curve at the left suggesting the former height of Jack's Mountain. Downward curves in strata are called synclines; upward curves, anticlines. Solid black indicates iron ore. After Lesley.

mountains. The Alleghenies are also in open folds, but this is not true of the Appalachians farther east. In most mountains of this type, however, the folding is more intense, the folds have been squeezed together, even turned over almost to horizontality, and finally some of them have cracked through, letting the upper side slip past the other, so that parts of folds have been pushed far beyond their original place in the series. Such thrust-

faults, as we have already seen, may move a whole mountain for many miles, as has happened in the case of the almost unscalable Matterhorn, which has been thrust some 50 miles northward from its original position, so that it is now a "mountain without roots," standing in a strange geologic environment. A similar example may be found in Chief Mountain in our own Glacier National Park, though here the distance traversed is but 15 miles (see figure, page 179).

The Alps represent fold-mountains in the full tide of their beauty, because their up-folding has been comparatively recent. In sharp contrast to them are the oldest mountains, the Killarney range of Ontario, whose glory has been taken from them by the "gnawing tooth of time," so that all that remains are their rumps or roots now beveled across by plains. Standing on such a plain as that of Ontario, the geologist reads in the pattern of the aligned rocks the story of mountains higher than the lofty Alps; and the beheaded Appalachians and the Urals likewise have a tale to tell of days when their summits soared many thousands of feet higher into the blue. The Canadian Shield is replete with these ancient rump-mountains, and it is against them as a firm buttress that the younger Appalachians and still more recent Rockies have been pushed and overfolded.

The sites upon which great mountain systems are to arise are determined, curiously, by the presence of zones of weakness in the earth's crust, so we have the apparent paradox that where the land sinks deepest, it also rises highest. Before a fold-mountain range can come into being, the vast amount of material of which it is made must be gathered together, and the only places in which

such tremendous thicknesses of sediments can accumulate in shallow seas are where the crust sinks as the superposed loads accumulate. These deeply sinking troughs are the geosynclines, "mothers of mountains."

When subsidence finally ceases, and the earth enters upon a stage of mountain making, pressures from the oceanic areas shove the accumulated load of sediments in the geosynclines into folds, and finally crush them together, with the result that the whole mass rises into a mountain range. During the process the geosyncline is foreshortened from one-fourth to one-half its original width, which is generally 50 to 200 miles. In mediterraneans, which are also sea-ways of great accumulation, the crowding together of the crust may be still greater, the original sea-way that gave birth to the Alps being probably four to seven times their present width.

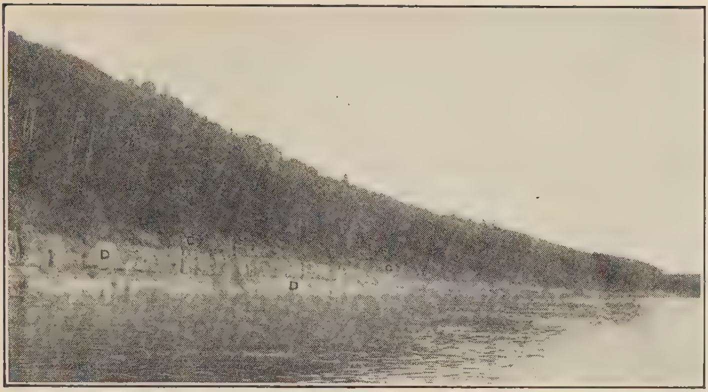
Outside of these sinking areas, crustal movement may give rise to mountains in quite another manner. During times of continental movement on a grand scale, the earth may be arched up lengthwise for thousands of miles, as happened during the Cenozoic era, when the Cordilleran mountains and the Great Plains were bowed up all the way from Omaha to the Pacific and from the Arctic to the Isthmus of Tehuantepec, the uplift amounting in places to 5000 feet. A relatively small dome of this character may be able to maintain itself, but one that covers very great areas must necessarily in part break down. Where the land remains up-arched, a new cycle of drainage will set in, and in the course of geologic ages mountains of erosion or residual mountains may be carved out of the surface of the plateau. Where the arch breaks down, great blocks of the crust are tilted upward and their ex-

THE TWO HIGH FAULT-SCARPS BOUNDING THE GREAT BASIN

Above, the east face, represented by the Wasatch Range near Salt Lake City, from a photograph by Shipler; below, the western wall, the Sierra Nevada, photographed by Louderback near Genoa Peak, where the scarp is approximately 4000 feet high.

posed edges form block mountains, with a steep fault-scarp on one side and a long gentler slope on the other. The first of these two types is represented on the great Cordilleran arch by the Black Hills of South Dakota and Wyoming, which stand on a persistent local dome that has been worn out by erosive agencies into a maze of "badlands" famous for their rich yield of remains of ancient life, and which have within their borders the highest land in America east of the Rocky Mountain front—Harney Peak, 4000 feet above the prairie country and 7200 feet above the sea. The second type is exemplified by the Sierra Nevada and the Wasatch, which present steep fault-scarps on either side of the Great Basin, and by the lower Basin Ranges which lie between.

The most localized and simplest mountain structures are due to upwellings from deep within the earth's crust of more or less large masses of molten rock, usually granite, which do not break through the covering strata, but push them up into domes. Commonly these are circular or oval in outline and probably not more than two or three thousand feet high, and they may be a few or many miles across, standing singly or in clusters. These are the so-called laccolithic mountains, exemplified by the Henry Mountains of Utah, the West Elk Mountains of Colorado, and the Little Belt and Judith River mountains of Montana. While the magma is rising, the roofing strata expand and crack radially, but during the process of cooling the mass shrinks, and blocks of the rigid cracked roof are let down differentially, some more than others. When the magma breaks through the crust, it forms mountains of extrusion, the volcanoes described in an earlier chapter.



Photograph by Kindle.

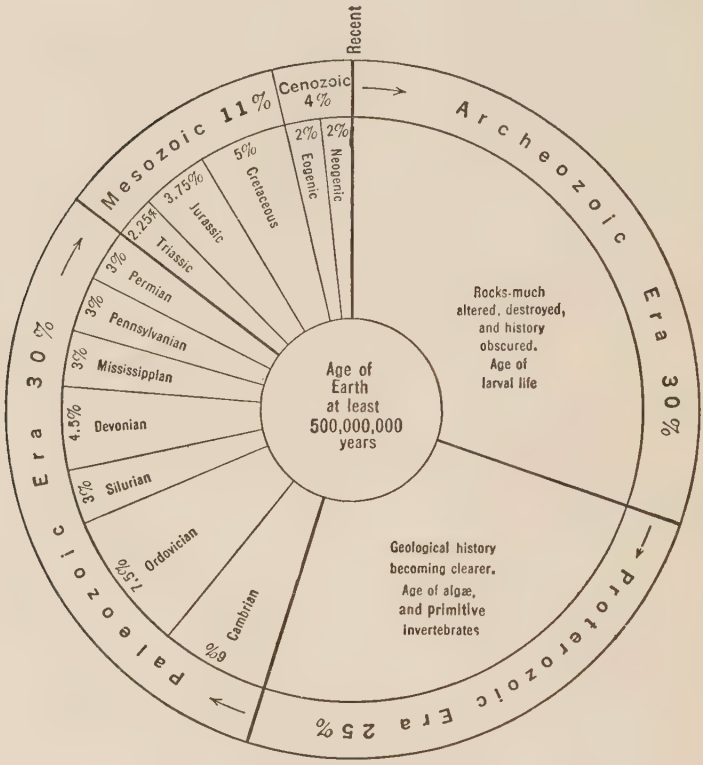
CRETACEOUS (C) RESTING ON DEVONIAN (D). LOST TIME INTERVAL BETWEEN, OF THE ORDER OF 100,000,000 YEARS. ATHABASKA

CHAPTER XX

THE GEOLOGIST'S TIME-TABLE

GEOLOGY has to deal primarily with the physical processes that have been at work since the earth changed from a shining star to an orb with a rock shell, shaping and reshaping its surface in obedience to forces acting deeper within its interior and in the atmosphere surrounding it. With the growing knowledge of these physical and dynamical processes it has, however, become apparent that they tend to work in great cycles, and geologists have learned to group into these cycles the multitude of different rock formations, each one of which was laid down at a definite time, and thus to construct a chronological background for geologic history. Against this background, obscurely at first but with increasing vividness, is played the thrilling drama of organic evolution, the long upward climb from amœba to man.

This orderly sequence of geologic chronology has been determined (1) through the actual superposed sequence



THE GEOLOGIC CLOCK

Note that the first two eras, about which we know the least, endured for more than half of geologic time, and that the succeeding eras are progressively shorter.

of stratified rocks; (2) through the degree of evolution attained by the fossils contained in the strata; (3)

through the breaks in the sequence of rock formations, when no record or but little was made; and (4) through the determined order in which the igneous rocks intersect or cut one another and the stratified formations.

Like human history, geologic history falls into major and minor divisions, and these in turn into smaller ones. The longest division is the era; the eras are the volumes in the book of geologic time, comparable in human history to the Christian era, and, like it, characterized by a striking change in events. The era terms are taken from the Greek, and are based on the state of organic evolution present (e.g., Paleozoic, from *palaios*, ancient, + *zoe*, life).

The eras are bounded by great changes, both in the physical aspect of the earth and in its life. These are due to times of great mountain making, known as revolutions, when the continents are not only highest but largest as well. In consequence of these events, the climates of the lands become more or less colder and drier, and the waters of the oceans are also affected. When these great changes occur, therefore, all life has to adapt itself to new environments or perish, and it is after these crises that we find the greatest changes among organisms.

A geologic era is composed of periods, the chapters in the geologic volumes. There is no regularity in their length of time, some being two to three times as long as others. Each period is characterized by one or more invasions of the lands by floods from the oceans, and the changes in the life of land or sea are far less striking than those between the eras. The names of the periods are generally taken from the regions in which the strata were first studied (Jurassic, from the Jura Mountains of

Geologic Chronology for North America

Eras and Length of Time	Periods and Length of Time	Advances in Life	Dominant Life
PSYCHOZOIC	**Recent**	Era of mental dominance	Age of Man
Cascadian Revolution			
CENOZOIC (Modern Life) 4%	NEOGENIC 2% **Pleistocene**, **Pliocene**, **Miocene**	(Periodic glaciation) Man-ape changing into man Culmination of mammals	Age of Mammals and Flowering Plants
	EOGENIC 2% **Oligocene**, **Eocene**	Rise of anthropoids, higher mammals, and birds Vanishing of archaic mammals	
Laramide Revolution			
MESOZOIC (Medieval Life) 11%	**Cretaceous** 5%	Extinction of dinosaurs Rise of archaic mammals and primates Rise of flowering plants	Age of Reptiles
	Jurassic 3.75%	Dominance of dinosaurs Rise of toothed birds and flying dragons	
	Triassic 2.25%	Rise of dinosaurs and reptilian mammals	
Appalachian Revolution			
PALEOZOIC (Ancient Life) 30%	**Permian** 3%	Rise of reptiles and ammonites Last trilobites (Periodic glaciation)	Age of Amphibians and Primitive Floras
	Pennsylvanian 3%	Dominance of coal floras and ancient insects	
	Mississippian, 3%	Rise of ancient sharks	
	Devonian 4.5%	Rise of amphibians, marine fishes, and land floras.	Age of Fishes
	Silurian, 3%	Rise of lung-fishes	Age of Fishes
	Ordovician 7.5%	Rise of corals, fishes, and land plants	Age of Invertebrates
	Cambrian 6%	Dominance of trilobites First known marine faunas	

Major Divisions (Based on physical evidence only)			Physical and Theoretic Organic Features	
Grand Canyon-Killarney Revolution				
PROTEROZOIC 25%	**Beltian** **Huronian**	Geologic history becoming clearer	Widespread glaciation Great iron age Oldest glaciation	Age of Primitive Invertebrates
Laurentian Revolution				
ARCHEOZOIC 30%	**Grenville** **Keewatin**		Rocks much altered and history obscured	Age of Larval Life

AZOIC TIME, of no life

COSMIC OR ASTRONOMIC TIME

GEOLOGIC TIME

Europe), or from some striking characteristic of the rocks which compose them (Cretaceous, from the Latin *creta,* chalk).

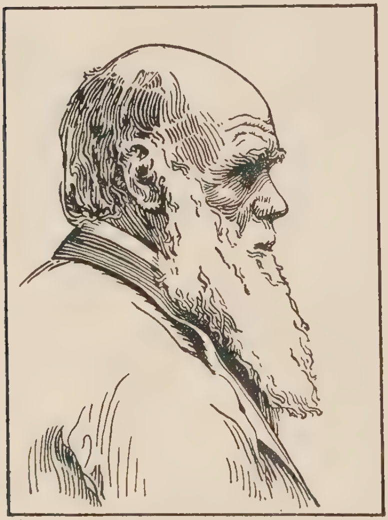
Since the oceans periodically flood the lands, and large parts of the continents are squeezed up into mountain ranges only to be again worn away, it follows that the rock record cannot be everywhere continuous and complete, but must be full of breaks. These are the "lost intervals" in the succession of strata, when no local record was being made, or when the record has been lost through erosion. Such times are known to be many, and the geologist must take them into account, but in the geologic time-table opposite they are not indicated.

To measure the duration of geologic time became a definite scientific aspiration during the past century. Hutton, the Scotch geologist who led the school of Plutonists in the eighteenth century, "found no vestige of a beginning, no prospect of an end." Twenty years ago geologists quite generally accepted 100,000,000 years as the probable age since the beginning of Archeozoic time, basing their estimates on the rate at which deposits are accumulated. Then came the epochal discovery that radium-bearing minerals like uranium and thorium break up into other elements with a final residuum of lead, and this at a definite rate that is measurable. Studies by the physicists along these new lines seem to show that the former figures must be multiplied about fifteen times. Even a billion years, however, is more time than geologists as yet know what to do with, although each year sees the discovery of new formations and new lost intervals.

CHAPTER XXI

EVOLUTION AND FOSSILS: THEORY AND DOCUMENTARY EVIDENCE

Do you wonder that the palæontologist walks a little apart from the ways of men . . . ? His field of vision embraces the whole of life. His time scale is so gigantic that it dwarfs to insignificance the centuries of human endeavor. And the laws and principles which he studies are those which control the whole great stream of life, upon which the happenings of our daily existence appear but as surface ripples.—W. D. MATTHEW



DARWIN, FATHER OF EVOLUTION

THE theory of organic evolution, which holds that life has been continuous, descending from previous life with change, is without doubt the grandest generalization of the nineteenth century, since it has not only transformed the method of study in biology, geology, and the social sciences, but has given a new point of view to all science, to art, and even to progressive religions. And to no class of thinkers is the truth of this theory more apparent than to those who study the life of the geologic ages as it is preserved in

the rocks. To these men, as they pass in review the actual documentary evidence for the long evolution of the organic world from the most primitive organisms to the complex plants and animals of to-day, "nothing is constant but change." How one type passes into another they cannot tell—perhaps no one will ever learn—but that it does so pass there can be no possible doubt in their minds, and the reason for the change seems to them to lie in the necessity for adaptation to a changing complex of living conditions, which they call environment.

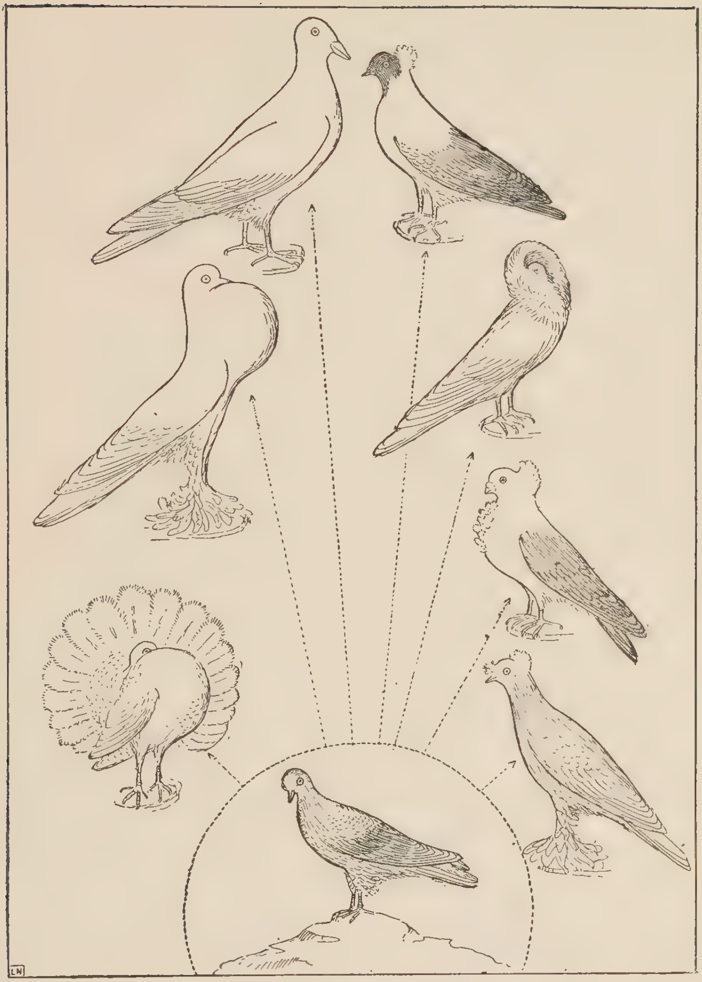
This changeableness of life has been noticed ever since the days of ancient Greece. Xenophanes (576-480 B.C.) knew that fossils were the remains of once living animals, but no Greek held that in them lay a chronology. The "Father of Natural History," Aristotle (384-322 B.C.), believed in an ascending series of more and more complex structures from living coral to man. In more modern times it was Galileo, Newton, and Laplace who gave the thinking world a scientific theory as to the transformations in the inorganic realm; and Buffon, Lamarck, Darwin, and Wallace who foreshadowed the present theory of organic evolution. Charles Darwin, however, is by general consent regarded as the father of the theory, since it was through his books, and chiefly through the epoch-making *Origin of Species*, published in 1859, that it was placed on a firm foundation.

Briefly, the procedure of evolution goes on through the interaction of seven conditions: (1) the prodigality of organic nature, living under (2) a constantly changing external environment and undergoing (3) internal changes, brings about—though by a process as yet unknown—(4) individual variation, which, because of (5)

the struggle for existence, leads through (6) natural selection to a fitness in adaptation which becomes more or less fixed through (7) heredity. In other words, in the struggle for survival, the possession of some slight variation may give one individual the advantage over the others, and those having the advantageous variation will live to pass it on to their offspring through heredity, so that in the course of time organisms better adapted to their environment will result. This constant adaptation to environment is shown by the succession of life throughout the geologic ages, which is in keeping with the procession of changed environments.

The prodigality of organic nature is beyond comprehension, and equally so is the wastage of individuals. More young are born each year than can possibly survive. The structurally higher individuals produce but few offspring, while lower ones cast upon the world many millions. In the consequent struggle for survival, the young are mercilessly weeded out because of unfavorable situations and starvation, snapped out of existence by predaceous enemies, or made sick unto death by extremes of heat or cold or by diseases. Success in life is the rare exception.

Through heredity, each species is said to "breed true" in its specific characters. Yet every breeder of plants and animals knows that this statement is not wholly correct, since no two individuals of any species are exactly alike. It is in these slight variations that the possibility for evolution lies, and the whole of it centers in the processes of reproduction, since the favored individuals transmit their valuable qualities to their offspring. The breeder selects the characters he desires to improve and



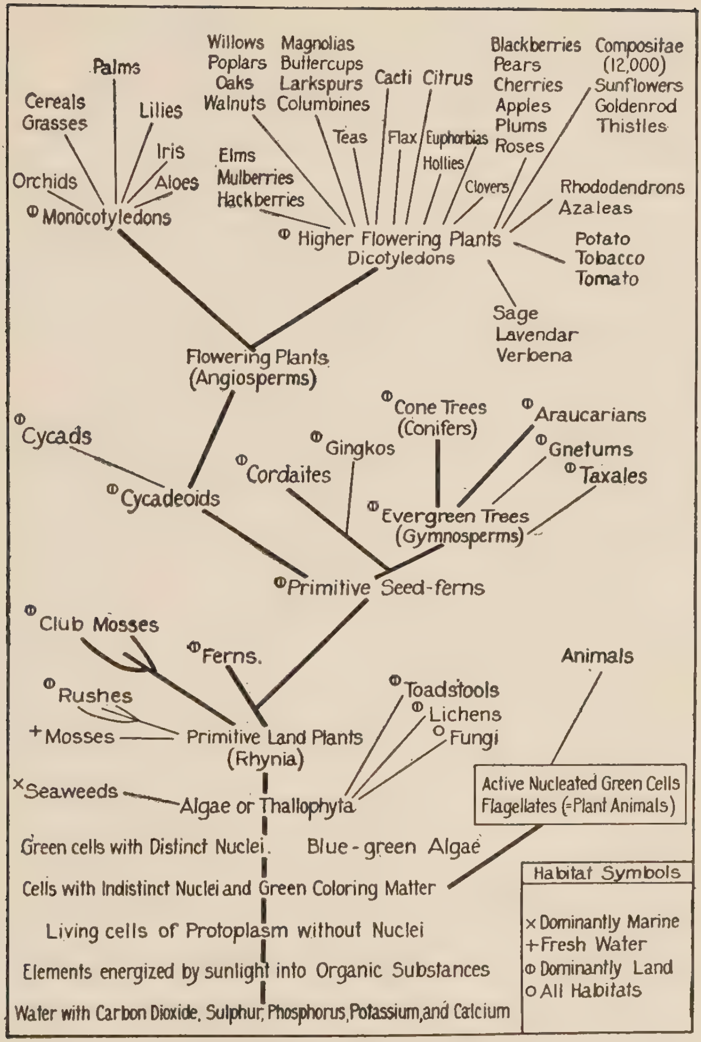
VARIATION AMONG PIGEONS

Produced by breeding (artificial selection), from the ancestral wild rock pigeon shown at the bottom. Above, left to right, fantail, pouter, giant, nun, jacobin, turbit, booted.

perpetuate, and accordingly picks out, to breed from, the individuals that have the quality sought for. Nature likewise in the long run selects for perpetuation the individuals with the organizations that are best fitted to the environment.

Probably the greatest factor in the upward progress of life has, therefore, been the necessity of meeting new environments. In previous chapters we have seen that the earth's surface is constantly undergoing change, and that when mountains are upheaved simultaneously in several continents, great changes in the humidity and temperature of the atmosphere result, bringing on arid climates and even glacial ones. In consequence, the balance between the members of floras and faunas is disestablished and over great areas there is brought about an added struggle for reëstablishment. Such times are especially fraught with danger to the animals that are specialized for living under the old conditions. Evolution is then especially rapid, blotting out parts of floras and faunas that have long dominated the earth, and giving some of the small and insignificant members of primitive stocks a chance to take the lead and rise into new races which in their turn quickly attain mastery over their physical and organic environment.

A great array of ancient forms of life is now known, and their appearance in geologic time has been determined. Geology is seen to begin with the absence of all life. Then scattering remains of seaweeds appear, and later low forms of marine animals. At the very beginning of the third great era, the Paleozoic, there is an abundance of marine forms, but for a long time there is no evidence of land plants, and an assemblage of plants

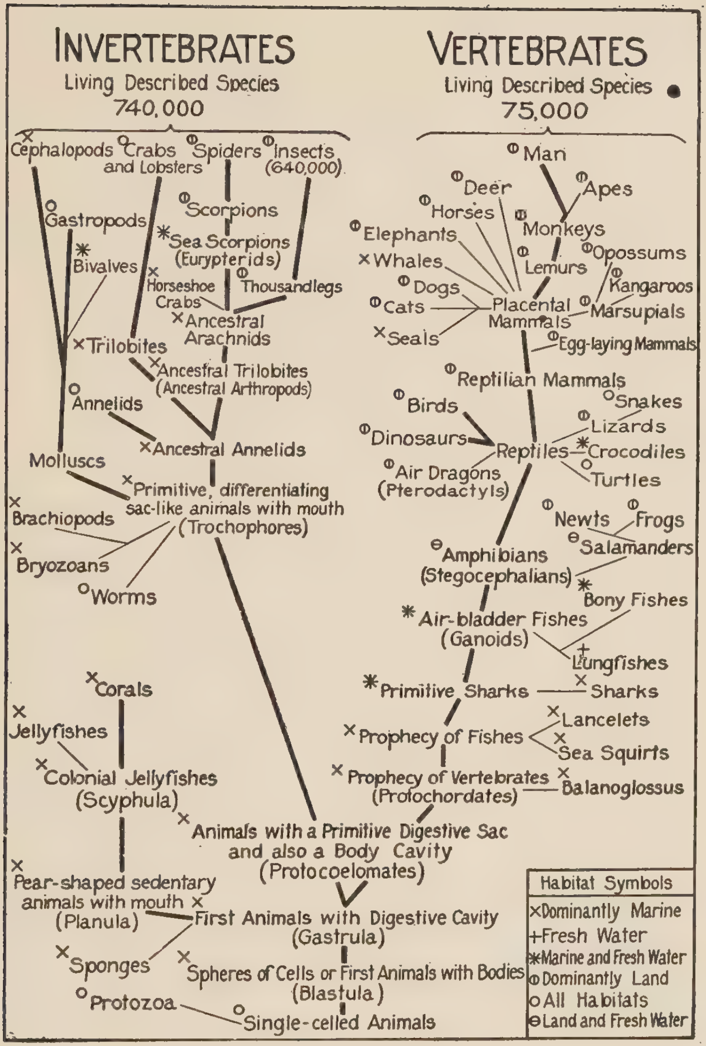


THE EVOLUTION OF PLANTS

Main lines of ascent in heavier black.

or flora does not appear on the land until considerably later. The earliest animals all lived in the oceans, and out of them in the course of time arose fresh-water forms and others that could breathe air, and therefore gave rise in turn to types that could live continuously on the dry land. Not a shred of evidence is at hand, however, for the existence of animals with backbones (vertebrates) until long after the backboneless forms (invertebrates) originated, the first representatives of the higher type being the fishes. Next came the amphibians, out of which developed the primitive reptiles. Reptilian birds with teeth appeared after the reptiles, and these gave rise to the modern toothless birds. Reptilian mammals, on the other hand, originated earlier than the birds, and through a long and slow process of evolution finally gave rise to the placental mammals, the highest type of animal life. Finally the line of mammals leading to man appeared first in the monkey-like lemurs, shortly afterward came the true monkeys, then the ape-man, and finally man himself.

All organisms, present or past, fall into one of two great divisions, the Plant Kingdom or Plantæ, and the Animal Kingdom or Animalia. These kingdoms are each again divisible like the parts of a tree, the trunk representing the kingdom, and the branches the divisions of smaller and smaller import, down to the individual leaves. Individuals that are more or less alike in their trivial characters are grouped together as species, for example, the domestic cats. Then all the species that have characters in common are included in a genus (plural genera); such are the various kinds of cats (lion, tiger, puma, leopard), all of which belong to the genus *Felis*. The genera in turn are combined into families, these into orders, or-



THE EVOLUTION OF ANIMALS

Main lines of ascent in heavier black.

ders into classes, classes into phyla, and phyla into kingdoms.

For easier reference, the various divisions above mentioned may be grouped as in the following example:

KINGDOM (Animalia)
  SUBKINGDOM (Chordata or backboned animals)
    PHYLUM (Vertebrata or vertebrate animals)
      CLASS (Mammalia or mammals)
        ORDER (Carnivora or carnivorous mammals)
          FAMILY (Felidæ, cats)
            GENUS (*Felis,* a member of the cat family)
              SPECIES (*Felis tigris,* the tiger)
                INDIVIDUAL

No actual count of the kinds of organisms living to-day has ever been made, but the estimates are near enough to give us a proper realization of their extraordinary diversity. About 200,000 kinds of plants have been described and not fewer than 815,000 animals. Of the latter, some 85,000 kinds live in the seas and oceans, and these, arranged according to their numerical variation, are molluscs, crustaceans, worms and annelids, fishes, echinoderms, coral-like forms, and sponges. Curiously, the fresh waters have the least variation, furnishing homes to about 20,000 kinds, one-half of these being fishes and the molluscs being represented by about 4000. By all odds the greatest diversification, therefore, is on the lands, which have about 710,000 kinds of animals; of these, however, 640,000 are insects, of which the average man knows so little, 50,000 are the more showy vertebrates, and 20,000 are snails, slugs, etc. Looked at in another way, there are more than ten kinds of living invertebrates for each kind of vertebrate.

Only about fourteen times in the history of life upon the earth have new animal phyla appeared. No new phylum has been evolved since the coming of the vertebrate fishes in the early Paleozoic, and no new classes

FOSSILS AS THEY OCCUR IN THE FIELD

Countless numbers of the circular echinids known as sand dollars (or, to the paleontologist, as *Echinarachnius*), weathering out of upended Miocene sandstone in King's County, California. Photograph by Ralph Arnold.

since the mammals and birds of the early Mesozoic. Hence all of the phyla trace their origin back to an early period in the history of the earth. Our knowledge of all this past life has come from a study of the organic remains preserved to us in the rocks, and it is the nature and

FOSSILS AS THEY OCCUR IN THE FIELD

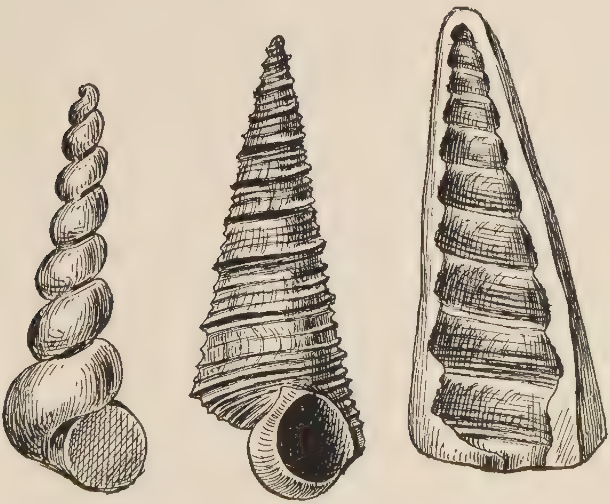
Bones of the ponderous dinosaur *Brontosaurus*, in process of excavation in the Bone Cabin quarry of Wyoming. Courtesy of the American Museum of Natural History, New York City.

significance of these life records, which are called fossils, that is to occupy our attention for the rest of this chapter.

Fossils are the remains of organisms that have lived in the geologic past, and the strata that contain them are the graveyards of the lost races connecting the past with the present. "The dust we tread upon was once alive," writes Byron. The degree of perfection in fossils may vary all the way from the imprint of a leaf in a shale or sandstone to an entire elephant preserving not only the

skeleton but all the soft parts and the stomach as well, as in the extinct mammoth frozen in the Siberian tundras. Fossils are, however, nearly always but parts of once living things.

Fossils occur in the stratified rocks and are as a rule the hard parts, such as external shells or internal skeletons. Of these, the actual or original structures may be present or to them may be added more mineral matter. Sometimes the original hard part has been wholly replaced by another mineral substance, forming a pseudomorph, or entirely removed, leaving in the rock a hole which is the mold of the exterior form; when this hole is filled up with rock, the filling is known as a natural



KINDS OF FOSSILS

Three ways in which the gastropod *Turritella mortoni* occurs fossil. In the center, the original shell; at the left, a natural cast of its interior; at the right, a natural mold of its exterior.

AN ANCIENT INSECT

One of the superbly preserved insects of the Kansas Permian (*Dunbaria*), showing color bands. Original in Peabody Museum, Yale University.

cast. Imprints are usually of leaves or of soft-bodied animals.

It is from these very important organic records that much of the geologic history of the earth has been unraveled. They reveal (1) the course organic evolution has taken, along with the former geographic distribution of plants and animals; (2) the sequence of geologic time, or chronology; and (3) the nature of the environment of the fossils, whether they lived in marine or fresh waters or on the dry land, and something about the depth and temperature of the seas and the climates of the lands.

The time value of fossils is of great import in historical geology. As all organic races, like individuals, have a span of life, and usually a short one geologically speaking, and as species and genera are constantly changing, their degree of evolution is more or less indicative of the time of their existence. In other words, each stratum has

AN EOCENE FISH

Skeletal remains clearly impressed on a slab of Green River limestone from Wyoming. Original in Peabody Museum, Yale University.

fossils, or combinations of fossils, peculiar to itself, certain forms being so diagnostic as to be called "guide fossils"; these can be used accurately in correlating the strata of a given age from place to place or even from continent to continent. For example, an elephant tooth indicates late Cenozoic time; the imprint of a leaf of a flowering plant (Angiosperm), post-Jurassic time; an oyster, post-Triassic time; and a trilobite, Paleozoic time.

In addition to dating the rocks in which they occur, fossils also afford testimony as to the environment in which they lived. Every species of the plant and animal world has a given home or environment known as a habitat, which may be dry land, rivers and lakes, or seas and oceans. Moreover, temperature varies between the poles and the equator, and organisms are therefore cold, temperate, or tropical in their adaptations. All of these differences in habitat are reflected in the fossils. For example, we have learned from many years' study of the corals that they are always to be found in the oceans, never in the fresh waters, and that they make reefs only where the water is permanently warm. Hence the fossil coral reefs (not merely an abundance of corals) that we find in certain ancient rocks of Spitzbergen tell us that the sediments composing these rocks were laid down in warm seas. Again, the leaves of tropical trees, when found in the strata of Greenland, testify to a warm climate at that high latitude when the leaves were buried. In other words, organic nature everywhere has the impress of its environment, and through a study of the interactions of nature in our own time we can learn how to unlock the riddles of the past.

CHAPTER XXII

THE DARK AGES OF THE EARTH'S HISTORY

Born of the stars, formed of star dust, and nourished by sunlight—
C. P. BERKEY

SPIRAL NEBULA

PHILOSOPHERS and astronomers have long been speculating on the origin of the earth, but prior to 1687 their attempts had no basis in fact. In that year Newton gave to the thinking world the principle of universal gravitation, namely, that each individual mass of material pulls from periphery to center, and that all concentrating masses pull on each other; the strength of the pull depending upon the mass and the distance apart. Using Newton's law as a basis, an hypothesis of earth origin was proposed in 1755 by Immanuel Kant, professor of mathematics and physical geography at the University of Königsberg. He conceived of space as originally filled with highly attenuated vapor-like material, locally varied as to mass, density, and attraction, which in time segregated into planetary masses. A somewhat similar theory was presented in 1796 by the French astronomer, Laplace, who thought of the solar system as beginning in luminous vapor filling all space

within and even beyond the orbit of Neptune, the outermost planet of the system. This vast ball of unbelievably attenuated gas, rotating and slowly contracting through loss of heat, he held to have gradually given rise, one after another, to nine gaseous rings, eight of which gathered into planets and one into a ring of asteroids. In turn, most of the originally gaseous planets also gave rise to rings, and these gathered into the moons.

Neither of these theories, however, withstood the criticisms brought to bear upon it, and it was left for two professors at the University of Chicago, T. C. Chamberlin, a geologist, and F. R. Moulton, an astronomer, to propose a more acceptable one, known as the planetesimal hypothesis. According to this theory, the gaseous sun is held to have come within range of a probably greater star, and, due to their mutual attraction, tidal action was set up, partially disrupting the sun; in other words, the solar system had a biparental origin. The far-flung exploded material, to which the name planetesimals was given, was thought to have been mainly dust-like, and to have taken on the form of long spiral arms revolving about the parent sun as if the latter were a gigantic pinwheel (see figure, page 243). Originally hot, this dust cooled quickly, but interspersed in it were large masses—nuclei for future planets and moons—which because of their size probably retained internally the heat derived from the sun. These so-called knots, because of their greater mass, are believed to have attracted to themselves, in the course of a tremendously long cosmic time, the planetesimals coming within their gravitational pull, and so to have built themselves up very, very slowly into the eight planets, their twenty-six moons, and the ring of

some thousand asteroids that lies between Jupiter and Mars.

The planetesimal hypothesis is, in turn, meeting with criticism and probably will in the course of time be modified. To harmonize it with the generally accepted idea that the earth was originally wholly molten, Professor Barrell of Yale changed the dust-like planetesimal conception to one of much larger masses, which he called planetoids, and which he postulated as ranging up to 485 miles in diameter. This larger planetoidal matter was, he thought, gathered in rather quickly, piece by piece, by the earth-knot, and plunging deeply into the central mass, made it all the hotter, with a liquid surface that was as level as that of the ocean but gradually cooled and crystallized into an uneven crust. That the substratum of the earth is still molten in places, volcanic eruptions bear abundant witness.

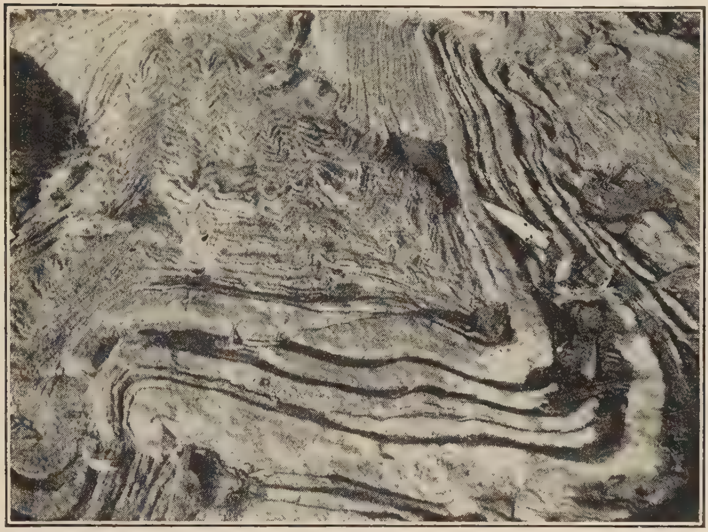
With the formation of a crust, Cosmic Time in the earth's history came to an end, and Geologic Time began. However, no one has yet consciously seen the smallest part of this original crust, nor discovered the oldest rocks that lie upon it, and this period of the earth's history has been called Azoic time—the lifeless era. During this time the various melts of the crust differentiated into rising masses of lighter rocks (granite) which eventually became protuberant continents, and greater sinking areas with heavier materials (the basalts of the substratum) which gradually gave rise to oceanic basins. These basins gathered the waters as they condensed out of the cooling original atmosphere made up of the gases escaping from the molten rocks. With decreasing heat came the introduction of rain and the weathering influences, the making

of sediments, and finally their gathering as strata in the seas and oceans. Eventually the sun's rays pierced through the thinned atmosphere, and this energy, in the presence of cooling waters with carbon dioxide, is thought to have made it possible for life to originate as tiny floating drops of jelly-like protoplasm. (For a further discussion of the probable beginnings of life, see Chapter XXIV.)

The oldest known water-laid strata, along with vast outflows of dark lavas and intruding crystalline granites,

SOME OF THE OLDEST KNOWN STRATA OF SEDIMENTARY ORIGIN

Pontiac schists, on Kinojevis Lake, Quebec, Archeozoic in age. They were tilted by subsequent crustal movements into mountains that have since been worn away. Photograph by M. E. Wilson, Geological Survey, Canada.



A FRAGMENT OF THE BASEMENT COMPLEX

Archeozoic limestone with inclusions of gneiss, altered and contorted by pressure and heat during subsequent crustal movements. Papineauville, Quebec. Photograph by Geological Survey, Canada.

are the characteristic rocks of the Archeozoic era, and with them geologic history begins. They are especially well seen in Canada and in Finland, and they reveal an extraordinarily complex record of event after event. None of the rocks are in their original condition, but all are more or less intensely altered and bent and gnarled by the intruding granites and the crustal pressures. Most of these rocks appear to be in hopeless confusion, and the geologist often speaks of them as the Basement Complex; they are truly the foundation upon which all later geologic formations rest.

The water-laid strata were originally sandstones (now

quartzite-schists), mudstones (now schists), and very great thicknesses of magnesian limestones (now marbles). That there was life in these ancient seas is shown indirectly not only by the presence of these limestones, but even more surely by that of beds of graphite, which is a carbon deposit of organic origin. The direct evidence of its existence, in the way of fossils, is, however, very scanty, consisting of remains of micro-plants of the kind spoken of as blue-green algæ, building the "cabbage-head" masses called *Eozoon*. It is thought that practically all the life then existent was not only water-living, microscopic in size, and of the lowest kinds of plants (Protophyta) and animals (Protozoa), but so soft-bodied and perishable as not to be capable of fossilization.

Archeozoic time endured seemingly for about 30 per cent of geologic time. Many mountain ranges had been made before the Laurentian Revolution at its close, but before the next era began all of them were worn away and the Canadian Shield was reduced to the vast Laurentian plain.

Then followed the iron-making Proterozoic era, which endured nearly as long as the Archeozoic (25 per cent). Time and again during this era vast lava flows occurred in Canada and with these came up great amounts of iron, about 70 per cent of the iron-ores used in the United States at present coming from beds of this age in the Lake Superior country. Toward the close of the era there was still more eruption of vast quantities of lavas, and with these came silver in Ontario and copper in northern Michigan.

Proterozoic strata of great thicknesses and of the common kinds of sediments are usually but little altered, and

in some areas (Montana, British Columbia, Grand Canyon) they look very much like those of the next younger era (Paleozoic). Apparently, then, the crust had become cooler and much thicker, the intruding igneous rocks less, and in consequence the strata suffered far less alteration.

The Huronian sediments o. Proterozoic age, now well exposed about Cobalt, Ontario, because of silver mining, have furnished one of the greatest surprises in geology: the discovery of the Cobalt tillite, a conglomerate of glacially scratched boulders deposited as till by continental glaciers and now hardened into tillite. They were later found to have a very wide extent in Canada, and recently others were made known from Australia. Their evidence shows plainly that even so far back as the earlier Proterozoic there was a widespread cold time. Much younger tillites, but still within the Proterozoic era, are also known in Norway, Africa, India, China, and Australia, so we may conclude that the climates ever since early in this era have varied between warm and cold.

Another significant fact to be read in Proterozoic rocks is the evidence for the increasing presence of the oxygen in the atmosphere that is so vitally necessary for animal life. To this greater supply of free oxygen the very thick carbonaceous deposits of plant origin indirectly attest, since plants free the oxygen from the carbon dioxide of the air, retaining the carbon; moreover, the red color of thick Proterozoic formations, which is due to atmospheric oxidation, is further evidence along the same line.

That life in the seas and oceans of Proterozoic time was far more abundant than in the earlier era is shown by the vast amounts of carbonaceous slates in certain forma-

tions (Animikian), and the many algal growths in these and younger strata. Then in the rocks laid down by the closing seas of this era we have the actual fossil remains of very primitive animals called radiolarians and of sponges, the trails of some crawling animal, and the tubes of worms (annelids). As the last group is high in the

PROTEROZOIC PLANT LIFE

Earliest of all life found fossil are the algæ, primitive plants that made globular masses of limestone. The above drawing illustrates a reef made by such organisms in the Proterozoic, found in Montana. After Willis.

scale of organisms, it can truthfully be said that there must have been a very varied marine life in the later Proterozoic, and that it was made up of floating and bottom-living kinds—a conclusion that is borne out by the abundant life of the next era. None of the shelled animals had yet, however, taken to using calcium carbonate

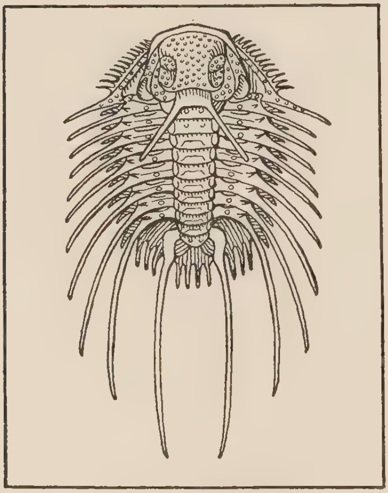
in the making of their external skeletons, and hence none of them are preserved.

At the close of the Proterozoic, mountains were made the breadth of Arizona, as is clearly revealed at the bottom of the Grand Canyon (see Chapter XIV). Even more extensive mountains arose throughout the Great Lakes region of Canada and may have extended southwest as far as Kansas and Oklahoma; these are the Killarney Mountains of the Canadian geologists. Finally, the Ocoee Mountains, which stretched from Virginia and North Carolina southwestward across Alabama, also came up in late Proterozoic time.

CHAPTER XXIII

PALEOZOIC TIME: THE ERA OF MARINE INVERTEBRATES

All progress in life, as reckoned in terms of man, has come through independence and through those lines of animal life in which independence has been maintained at any cost. Dependent races of animals have sought or accepted dependence as an easier mode of living, either waiting upon the unconscious forces of Nature, waves and winds, or on the normal activities of other animals. Such dependence has entered in some degree upon all primitive stocks of animal life and from such racial dependence there has been no escape. The lines in the animal world along which links in the chain of advancement have continued unbroken, are but few; the rest have run out into culs-de-sac where all hope is abandoned. . . . In greater measure than we may have suspected the clue to human destiny and social adjustment lies concealed in the rocks beneath our feet.—JOHN M. CLARKE



A SPINY TRILOBITE

WE have now passed in review about one half of the grander events in the earth's history (Archeozoic 30 per cent, Proterozoic 25 per cent), and, extraordinary as it may appear, in all this time life, as recorded in fossils, is most meager. In fact, organic remains are so rare, even in the Proterozoic, that we do not know from them alone the general course

of evolution that the most primitive animal life has taken. And yet at the very beginning of the third era, the Paleozoic, there is not only an abundance of fossils, but, what is even more significant, a highly varied assemblage of marine invertebrates, ranging from the lowest groups to the highest. It is true that all are still of the primitive kinds within each line of descent, that there is in the Cambrian but a single possible fragment of fish and not a trace of land life; nevertheless among these marine backboneless forms (invertebrates) occur the progenitors of all later kinds of water- and land-living stocks. This great outstanding fact in historical geology means that a varied marine life was in existence long before the Paleozoic, and the probable reason why these ancestors are not preserved in Proterozoic strata is because none of them had acquired the habit of using calcium carbonate for the making of protecting skeletons and they therefore lacked the hard parts necessary for preservation.

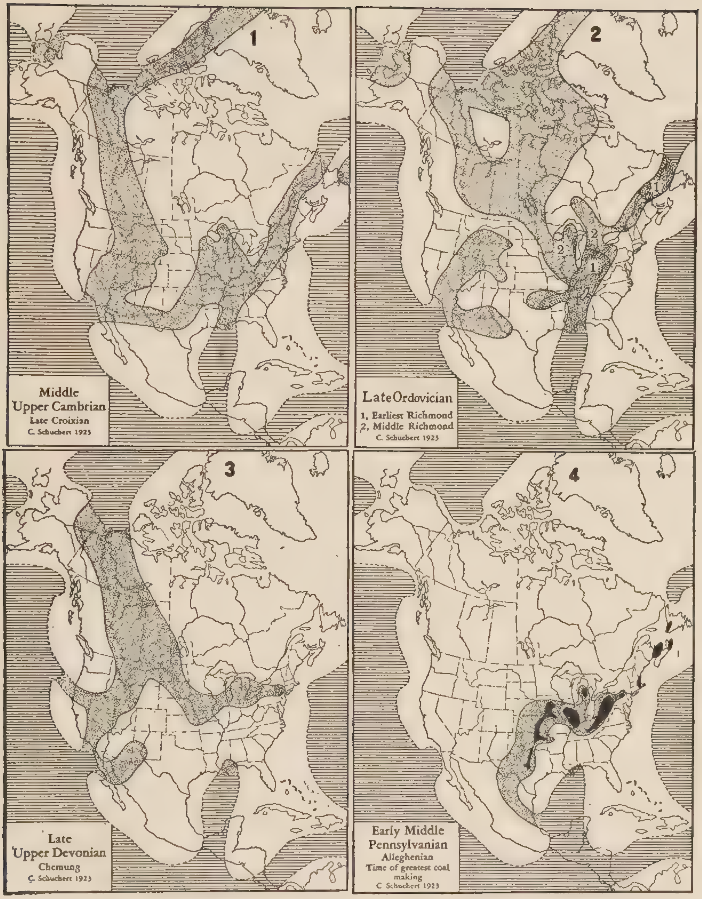
North America is wonderfully rich in a long succession of Paleozoic formations that abound in fossils, and this is especially true for the eastern half of the United States and Canada. No other continent is so rich in this history; the Paleozoic strata of Europe are as a rule much disturbed and metamorphosed, making them very difficult to interpret, but in North America, over vast areas west of the Appalachian Mountains, the fossiliferous strata lie almost as they were deposited, although of course much consolidated by time. When these strata weather away, they usually yield their entombed organisms freely, and innumerable kinds of fossils are to be had by those who will look for them throughout the great valley of the

Mississippi River, the Great Lakes country, and Ontario.

With the beginning of Paleozoic time, this abundance of fossils furnishes a ready and reliable means of correlating the formations not only from place to place but even between continents. Hence we have in most post-Proterozoic strata a far more detailed classification of the events, and also a greater knowledge of two parallel evolutions, that of the rocks and that of the organisms. As these two sets of phenomena are constantly interacting, they are checks upon each other in the determination of the actual events that happened at any time at a given place. In other words, because of the abundance of fossils in the Paleozoic and subsequent times, we are able to decipher a much more detailed history of the earth and its life than is the case in earlier eras.

Nevertheless there is nowhere a complete record of Paleozoic time, and even when one is pieced together from all the known occurrences it is still incomplete, though the gaps are not thought as a rule to represent long intervals of time. The longest array of superposed strata is to be seen in the area east of the Mississippi River and in the Appalachians from northern Pennsylvania to southern Alabama.

The reason for this widespread occurrence of Paleozoic rocks lies, of course, in the geography of the time. If marine fossils are now found in the center of the continent, it follows that there must have been a sea in that region at the time the rocks containing these fossils were laid down, because sea animals can live only in marine waters. Such floodings of the seas over the lands were frequent and often of great extent during the Paleozoic, the major ones covering from 30 to 50 per cent of the



PALEOZOIC MARINE FLOODS

Maps showing four different invasions of North America by the Paleozoic oceans. Solid black in the Pennsylvanian map represents coal areas.

continent at least nine times (Cambrian, Ordovician (3), Silurian (2), Devonian, Mississippian, and Pennsylvanian-Permian periods). At but one time later on (Cretaceous) were the floods so general over North America.

How deep these inland seas were can be told in a general way from the sediments and the entombed fossils, and the conclusion derived therefrom is that on the average they had a depth of less than 600 feet. Nevertheless, the sediments laid down by the seas during Paleozoic time outside of the geosynclines are rarely less than one-half mile in thickness, while in the geosynclinal areas their average depth is between three and six miles. This shows the remarkable inconstancy of the surface of ancient North America in relation to sea-level. Broadly considered, this continent, like all others, is an upstanding part of the earth's crust, composed of lighter rocks (essentially granites), but while large marginal areas of it were at no time during the entire Paleozoic beneath the sea, far more than one-half of the central part of the continent in the course of this era sank to the extent above indicated. Nevertheless, the continent at no time had other than shallow seas.

Into these Paleozoic seas the rivers of the time poured their sediments and formed great deltas. During the close of the Ordovician period there came into being the Queenston delta, which laid down reddish mudstones and sandstones from Niagara Falls to southeastern New York and then southwestward in the Appalachian geosyncline into Virginia. The largest of all deltas began to appear in late middle Devonian time, accumulating materials to a depth of 13,000 feet from the Catskills southwestward into Virginia. Another delta of this same time lay in

the area of Gaspé, Quebec. Finally, three deltas began to develop in the Appalachian geosyncline during the time of the coal swamps, one in eastern Pennsylvania (Pottsville), another in Virginia (New River), and the largest of the three in Alabama (Cahaba).

In the strata laid down in the seas during the opening period of the era, the Cambrian, all the great groups of invertebrate animals are present. These faunas did not, however, in the least resemble the marine assemblages of to-day, not only because they were all primitive life, but mainly on account of the abundance of Cambrian stocks that are now either extinct or greatly reduced, and the presence in our modern faunas of stocks that have risen into a prodigality of form in no way predictable from their Cambrian ancestors. To-day the seas swarm with highly varied molluscs or shellfish and with true fishes, but during the earlier Paleozoic the shelled animals were insignificant in size and variety, while the fishes were tiny and very rare indeed. Instead, the Cambrian seas were characterized by a vast variety of scavenging and predaceous trilobites, along with a horde of sedentary brachiopods, while snail shells (gastropods) were scarce, small, and not at all varied or beautiful, and of other molluscs there were hardly any. Other kinds of life were not significant in the economy of the Cambrian seas, but undoubtedly the seaweeds were then as varied and abundant as they are to-day.

Trilobites (see figures, pages 252 and 258) were curious looking segmented animals with the body divided into three longitudinal lobes (trilobed), with an upper shell or carapace and a thinner shell on the ventral side, with many pairs of double legs, and, like the flies, with com-

SEA LIFE OF DEVONIAN TIME

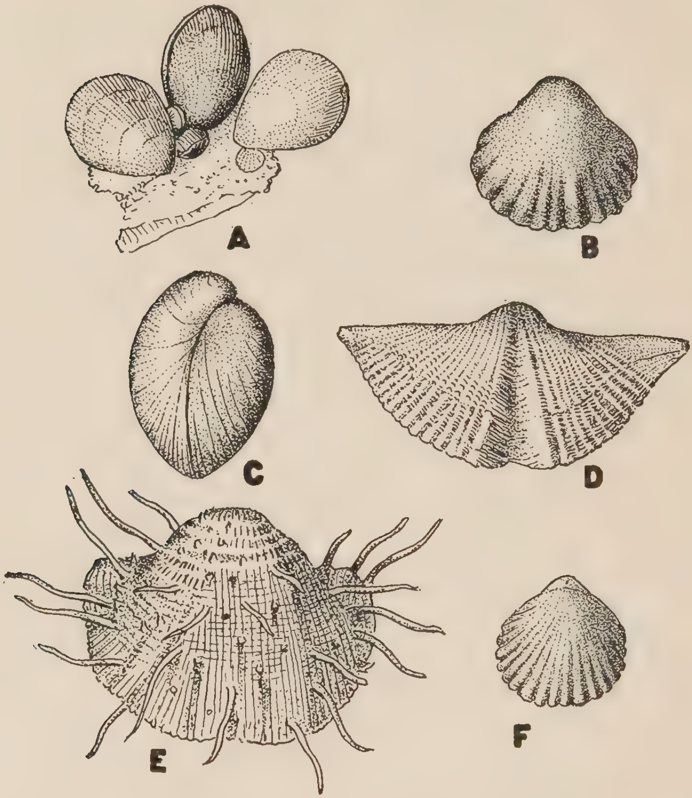
As restored in the New York State Museum at Albany. The plant-like animal at the left is *Scytalocrinus*, a crinid; in the center is the cephalopod *Gyroceras*, attacking *Homalonotus*, a trilobite; the group at the right includes other trilobites and seaweeds.

pound eyes the lenses of which sometimes reached the astonishing number of 30,000 in the two great eyes of the head. They are without representatives to-day, but in them existed the prophecy of coming lobsters and crabs.

Trilobites appear ready made, as it were, and already highly varied in the Cambrian, showing that the stock was a very ancient one, with its origin far back in the Proterozoic. At the end of the Cambrian they began to show a decline in numbers and variety, and their death knell was undoubtedly sounded by the rising cephalopods that began to feed upon them at the close of the Cambrian. These new carnivorous aggressors were active swimmers with great eyes, and were protected by a heavier shell, while the trilobites were sluggish and poor swimmers, with coverings that afforded little protection against the firm biting beaks of the cephalopods. Moreover, during the Silurian the fishes as well began to menace the trilobites, and in this unequal battle the latter finally succumbed, the last ones occurring in Permian time.

Other common animals of the Cambrian, and the most common of all throughout the succeeding periods of the Paleozoic, were the brachiopods, more than two hundred kinds of which are still living in the oceans. They are always marine forms, anchored to the ground or buried in it, and encased by two valves that are usually made of calcium carbonate. Their valves are hinged, as in the clams and oysters, but the two groups are in no way related. The brachiopods are, as it were, a by-product of nature, since nothing higher or different was evolved out of them. (See figure on page 260.)

After Cambrian time followed the Ordovician and Silurian periods, when the seas were full not only of



FOSSIL AND LIVING BRACHIOPODS

A, colony of living *Terebratulina;* B, *Gypidula,* common during Silurian and Devonian times; C, *Meristella* of the Devonian; D, a "winged" shell, *Spirifer pennatus;* E, *Productus horridus,* of Pennsylvanian time; F, *Camarotœchia,* common in Silurian and Devonian strata.

primitive molluscs, but as well of brachiopods and corals, and to a less extent of trilobites. Then also appeared the prophecy of fresh-water fishes, and on the lands a suggestion of the coming of floras. It was said earlier that

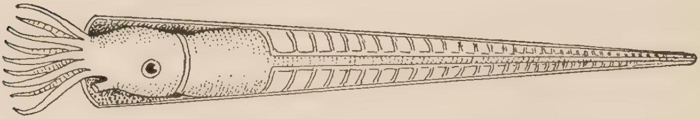
in the Cambrian there were a few kinds of small marine snail shells, the gastropods, which crawled around on their bellies and wore their houses fastened upon their backs. Small and insignificant as was their beginning, they were nevertheless the heralders of most of the life of the seas and oceans from the Ordovician onward, for these primitive Cambrian forms were the progenitors of the great phylum of Mollusca (soft-bodied animals), which includes the periwinkles and snails, the two-shelled

PALEOZOIC MARINE GASTROPODS OR SNAILS
Left to right, *Lophospira, Murchisonia, Bellerophon.*

clams and oysters, the chambered-shelled nautilids and ammonites, and the shell-less squids and devilfish. More than 20,000 kinds of gastropods alone are now living in the seas and rivers, while an equal number creep over all the dry lands not covered by snow and ice. Throughout geologic time we see this wonderful phylum constantly increasing, though certain of the stocks die out all along the line.

The extraordinary sluggishness, poor vision, and very low mentality of the gastropods are lost more and more in their higher descendants, the alert and keen-eyed ceph-

alopods. These arose in the Cambrian and at first also lived in cone-shaped shells with air-filled chambers; later some began to bend and coil their chambered shells like a watch spring, giving rise to the beautiful pearly nautilus that is still living in the Pacific Ocean; finally some even got rid of their protective but encumbering shell and became the alert and predaceous squids, the larger ones of which to-day fight even the whales. They are not only the largest of all invertebrates, but as well the highest expression of mentality that the oceans have ever



A PRIMITIVE CEPHALOPOD

One of the primitive chambered-shelled cephalopods (*Orthoceras*) so common in the Ordovician and Silurian, when certain forms had a length of 15 feet. Later in race history, the shells are curved, then loosely coiled, and finally tightly wound as in the ammonites (page 315).

produced, and yet none of them could adapt themselves to the dry lands and so rise into something higher and more intelligent.

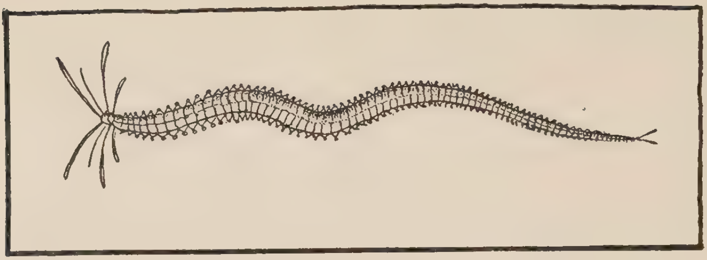
Still another group of molluscs, the degenerate and bivalved lamellibranchs, the tribe to which the clams and oysters belong, had their origin in the Ordovician, developing out of the gastropods. When first born, these creatures have head and eyes even to-day, but soon lose both on encasing themselves in their pair of shells. In consequence of this degeneracy, their chief rôle in the economy of nature has ever been to furnish an abundant

supply of food for many kinds of animals from starfishes to man.

Certain other plantlike animals, the lime-secreting corals, did not arise until the middle Ordovician, but since Silurian times have abounded in all the warm seas and oceans, making widely distributed reef limestones. They are, however, always fastened to sea bottoms, and so have given rise to no other group, since all anchored life is doomed not to rise into higher kinds, and, conversely, when better stocks take to a sedentary existence they are also destined to degenerate. Activity and alertness are ever rewarded with a more complex body structure and a more sensitive nervous system, resulting in higher mentality.

In the middle Ordovician, another striking stock comes into prominence—the plated and spiny-skinned echinoderms; here again most of them are anchored (cystids and feather-stars or crinids, figure, page 269), and even though some of them become free, like the starfishes and the spined sea-urchins, these also have always remained very sluggish scavengers and carnivores. Nevertheless the kinds and numbers of echinoderms are still prodigious in marine waters, and at times in the Paleozoic the skeletons of crinids accumulated into limestones many feet thick. To-day the phylum shows no signs of decline or extermination, and yet it has given rise to no higher stock.

All of this shows that although animals may be very simple in structure and even without a nervous system, as are the corals, or so low in organization as to be nothing more than lumps of living matter, like the land-living slime molds, or parasitic degenerates that know no more than to suck the blood of other individuals, there is yet



A MARINE WORM

Nereis, one of the common marine worms, or annelids, of to-day. Similar ones lived as far back as the Proterozoic era.

plenty of space for them in Nature. They remain, however, as mere "expression points" of arrested and dependent organic development.

We have as yet said nothing of the actively wriggling marine worms, the segmented and highly iridescent annelids, which are not, however, the same as the lower worms of which the earthworms are the most widely known. Because the annelids are soft-bodied, they are very rarely met with as fossils, but occasionally they have left their record in the fossilized tubes in which they once lived, or in their burrows in muds and sands. Annelid tubes are known as far back as the late Proterozoic, the Cambrian is often replete with their burrows, the middle Cambrian at Field, British Columbia, has yielded a variety of imprints of the entire body form and even of the intestinal tract, and ever since middle Ordovician time their teeth are common fossils. It is therefore safe to say that annelids were present as early as the middle Proterozoic, and as the metamorphosing stages in the growth of trilobites show that they were derived out of annelids, these ancestral worms must therefore have originated long be-

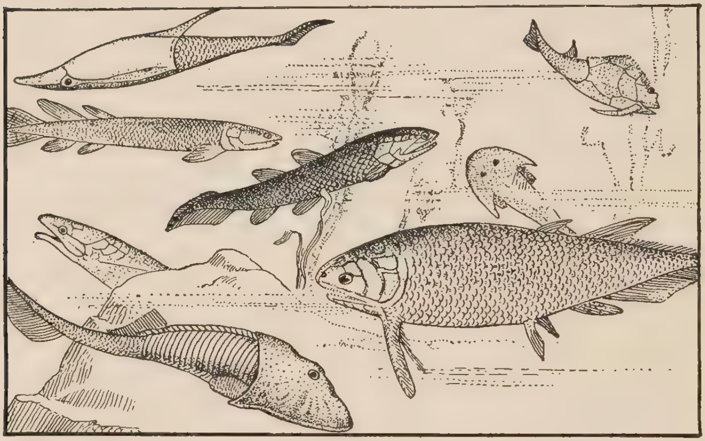
fore the Cambrian. These are most interesting genetic facts, and biologists have long been holding that out of the annelids probably have also come the progenitors of the fishes. This story of the coming of the fishes and the higher vertebrates is, however, so significant that we will develop it further in the next chapter.

Each spreading of the early Paleozoic seas over the continents provided favorable habitats for the great host of marine life, which therefore flourished abundantly. These pleasant living conditions did not, however, continue indefinitely, but were interrupted from time to time by the partial or complete withdrawal of the seas from the continents, and by the uprise of great mountains, as the result of renewed crustal activity.

We have already seen how Cambrian history opened with at least three areas of high mountains, the Ocoee of the South Atlantic states, the Killarneys of Canada, and the Grand Canyons of Arizona. Like all mountains, the grandeur of these was of short duration geologically, and they were worn away by weathering influences before the close of the Cambrian. Then for a long time the crust of nearly all of North America remained stationary and but little above sea-level, the scenery being monotonous. Local mountains arose, however, first at the close of the Cambrian in Vermont and adjacent Quebec, and again later, but more extensively, throughout easternmost New York into New Jersey and Pennsylvania, the last named being the Taconic Mountains of late Ordovician time. During the Silurian many volcanoes were active, not only in southeastern Maine, but throughout New Brunswick and Quebec as well; they probably were symptomatic of the crustal unrest that found greater expression in the

mighty Caledonian folding of Ireland, Scotland, Norway, and Spitzbergen toward the close of the Silurian and during the early Devonian.

With the next period, the Devonian, we come to one of the most picturesque portions of Paleozoic time, because now we find life not only in the seas, but in the



STRANGE FISHES OF DEVONIAN TIME

These fishes were armored, in some forms over the head only. *Pteraspis* (upper left) and *Cephalaspis* (lower left) have no lateral swimming paddles or fins. *Pterichthys,* the "winged fish" (upper right) has a curious pair, located well forward. *Holoptychius* (lower right) has four which look more like fins, and which have indeed a special evolutionary significance, since out of such organs probably developed the legs of vertebrates. After Lucas.

rivers and on the lands. The Devonian waters, salt and fresh, begin to be alive with fish, the monotony of the somber landscape is varied by plants and even by local forests, and the dry lands have inhabitants in the form of air-breathing spiders, scorpions, thousand-legs, and even four-legged amphibians, the ancestors of the frogs.

This land life, a few representatives of which were present already in the Silurian, comes down to us preserved in thick series of deposits laid down by fresh waters in valleys between mountains, or in great coastal lagoons. All of these rocks show evidence of dry climates in their prevailing red color and in the ripple-marks and sun-cracks that are indicative of long exposure to dry air. In Scotland, these Old Red Sandstones, as they are called, were among the earliest strata to attract the attention of geologists, and their American counterparts are to be found in central New York and in Gaspé, Quebec.

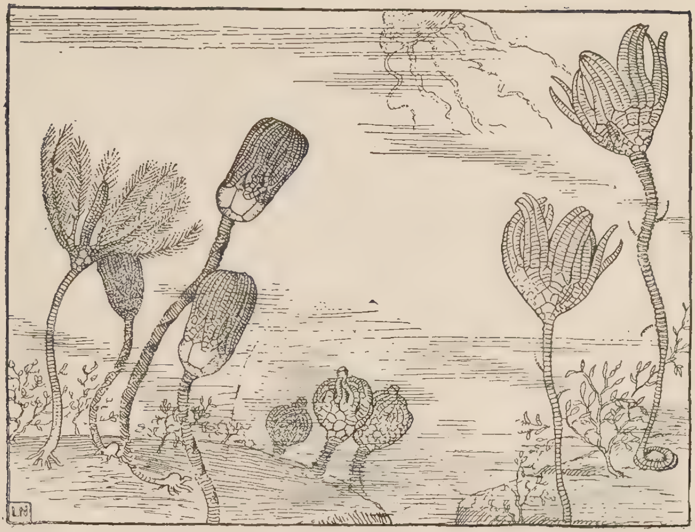
The Devonian fresh-water fishes were already varied enough to include members of several great groups, over a hundred different kinds being known. Their remains are, moreover, so plentiful in places such as the Orkneys that Hugh Miller, an early Scotch geologist, who wrote extensively on the Old Red, called this region a "land of fish." Among them were the "bony-skinned" ostracoderms, which include the so-called "winged fishes" such as the strange hump-backed *Pterichthys*, with decided armor over the front part of the body and with armored paddles. These were aberrant types, with no future, but associated with them lived a more significant group, the lung-fishes, of which we shall say more in the next chapter.

The aridity of the later Devonian was a natural consequence of a widespread emergence of the continents, North America being practically all dry land at the close of the period. This emergence was consonant with the marked mountain making that in middle Devonian time blotted out the Acadian and St. Lawrence geosynclines forever, and elevated all of the New England states and

the Maritime Provinces of Canada into the majestic Acadian Mountains. No greater earth movement ever befell this region. The northern half of the British Isles was also the theater of igneous action on a large scale, as was the region around the Christiania Fiord in southern Norway.

The crust of North America then remained quiet until toward the close of Mississippian time, when the Cahaba Mountains of Alabama, the Ouachitas of Arkansas and Oklahoma, and the Windsor Mountains of Nova Scotia and New Brunswick arose. The marine life of the Mississippian period presents nothing of particular interest, being characterized mainly by the abundance of the beautiful feather-stars or crinids, which resemble plants so closely that they are often called sea-lilies, and by a rapid evolution, followed by an equally rapid decline, among a group of sharks that were apparently shell-feeders. The succeeding Pennsylvanian period is, however, noteworthy for marked instability of lands and seas, resulting in great swamps in which flourished a tropic luxuriance of plants (see figure, page 86), and which, when filled up with this decaying vegetation, became transformed into the coal beds of to-day. These coal forests had among their denizens the largest insects ever known, one of them, of the dragon-fly type, reaching a wing-spread of twenty-nine inches, while some of the eight hundred kinds of cockroaches—the insect "aristocrats" of their time—attained a length of four inches. Along with these were the earliest amphibians of which we shall learn more in the next chapter.

With the Permian, we come again to conditions of aridity, registered in the well-known red beds of our own



CRINIDS, MOST BEAUTIFUL OF MARINE ANIMALS

The majority of the fossil crinids were attached to the sea bottom by stalks. Gregarious in habit, they occur in abundance only locally, and this is as characteristic of them to-day as it was millions of years ago when their skeletons were making the thick crinid limestones of Mississippian time.

Southwest. These dry Permian times have likewise left us a very valuable legacy in the shape of vast salt beds in Texas, New Mexico, and Oklahoma.

During middle and late Pennsylvanian and well into Permian times, the earth's surface was in motion, not only in North America, but as well in most of the continents, and it was arched over vast areas or folded in smaller ones. In Nova Scotia the Cobequids were the first to go up, then the Ancestral Rocky Mountains of Colorado and New Mexico; and finally the entire area of the Appalachian geosyncline from Newfoundland to Ala-

bama was squeezed together into the grandest ranges of mountains that ever existed in eastern North America. All of these mountains arose out of the geosynclines inside the borderlands of the Atlantic and the Gulf of Mexico, and none appear to have been made in the far west.

In middle Pennsylvanian time were also made the Paleozoic Alps of Europe, whose rumps of massive rocks may be seen in Germany, France, Belgium, England, and Ireland to-day. Mountains likewise arose in the Pyrenees, the Spanish meseta, Corsica, Sardinia, and the Alps. The folding of the Urals began in later Pennsylvanian time and attained its climax in the Permian. Even in Armenia, central and eastern Asia, South Africa, Australia, and the Andes can be followed the traces of the mountain making movements of this time.

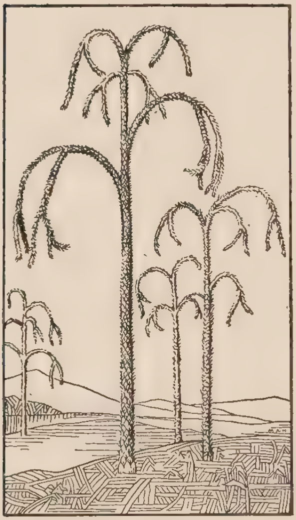
The earlier, more local mountains, as they arose, probably affected only the land life of the more immediate regions, but the great crustal unrest toward the end of the era, which was practically world-wide, took on the nature of a revolution and had far-reaching effects on the climate and life of the time. So vast were the continents and so high the mountains that the previous warm climates became generally deranged and reduced in temperature. A very marked glacial climate appeared in middle Permian time, and, curiously, the continental icefields of this time were greatest between 5 and 40 degrees south of the equator in Africa, Australia, and South America, and far less to the north of the tropics in India. The vicinity of Boston also has local tillites. Later, deserts galore came into existence in the northern hemisphere, in Africa, and South America, and the vanishing seas deposited salt as never before or since.

In consequence of this mighty crustal revolution, the altered climatic and environmental conditions brought on a critical time for the life of the lands. In the southern hemisphere most of the Coal Measures swamp flora was wiped out by the cold climate, and in the northern one by the aridity. The ancient insects vanished and the amphibian-reptilian world was in a state of flux due to its struggle to adapt itself to the stress-climate conditions. In the sea, however, there was no sweeping alteration, and hence we see here a more normal speed in evolution, the Paleozoic life changing more gradually into that of medieval time. Most of the change in marine life was due to the blotting out of certain of the characteristic types of Paleozoic invertebrates: the trilobites, long on the decline, vanished completely, as did most of the primitive corals and some of the brachiopods, while the chambered-shelled cephalopods (ammonites) and the gastropods and bivalves became more and more varied.

HELIOPHYLLUM, THE STONY SKELETON OF A COMMON DEVONIAN CORAL

CHAPTER XXIV

THE CLOTHING OF THE LANDS WITH VEGETATION



ARCHCOSIGILLARIA, A DEVONIAN TREE

IN the previous chapter we learned something of the great variety of invertebrate life that pulsed in the seas of Paleozoic time, and of the coming and going of the marine floods and the mountains on the North American continent. In the next two we are to see the peopling of these ancient lands—a most significant and fascinating story—first by the plants, then by the invertebrates that came out of the marine and fresh waters to feed upon the plants, and finally by the fresh-water fishes out of which were to come the four-legged vertebrates.

The marine waters, although they teem with myriad forms of life, were not destined to witness the most significant portion of the drama of organic evolution. Constancy of environmental conditions is characteristic of the seas and oceans; their inhabitants are not often called upon to meet great crises, and when these come they are

only in the nature of marked temperature alterations over wide areas. Consequently the accentuation of the struggle for existence that ends in the perpetuation of decided advantageous variations is lacking, and the life of the seas to-day needs no higher intelligence than it had in Paleozoic time. Then as now the strongest and keenest members of the invertebrate sub-kingdom are the giant cephalopods; of the vertebrates, the fishes of to-day probably rate no higher in mentality than did those of the Devonian; and the few reptiles and mammals that have at various times gone back to the seas scarcely rank among the highest of their kind. It is the lands, therefore, with their great variety of living conditions and their susceptibility to alteration on a tremendous scale, that have been the laboratories wherein nature has worked out most of her experiments for the perfecting of organic structures with the highest mentality.

The primary need of all living creatures is food, and in the last analysis it is the plants that furnish it. Until plants had become established upon the lands, therefore, the latter were impossible dwelling places for the animals, and it is consequently of interest to see how they came to don their present mantle of vegetation.

Geology cannot hope ever to discover in the form of fossils the first evidences of life, because primordial life was not only minute and very short-lived, but also highly perishable and without fossilizable parts; nevertheless the low plants known as algæ are found fossil as far back as the Archeozoic. The living world, however, has such an abundance of lowly organized life that biologists can safely infer therefrom, keeping in mind the appearance of life throughout the geological ages, what the first life was

like and what was its probable course of evolution into more complex forms. Most biologists are agreed that life probably originated in the sunlighted portions of the ocean as single-celled microscopic floating plants. Certain organic chemists, on the other hand, prefer to think of it as starting in hot waters of volcanic origin, a view supported by the fact that some of the most primitive forms of algæ (blue-green forms and bacteria) live to-day in boiling hot waters such as those in Yellowstone National Park (150° to 180° F.).

The oceans to-day swarm with microscopic life, the "plankton" of the seas, and in the beginning of geologic time, life could scarcely have been of any other sort. The origin of life is generally believed to have been due to sunlight falling on waters containing, besides carbon dioxide, traces of sulphur, phosphorus, potassium, and calcium, and thus building up carbon colloids that eventually evolved into organic compounds (protoplasm, the basal substance of all life). The life-giving sun's rays penetrate to depths of about 500 feet, and hence some of this plankton may well have adapted itself to living on and becoming attached to the bottoms of the shallow seas. Here it was able to build up a greater body composed of many cells, and hence one heavier than water and with a much longer life span, many cells together having more assurance of prolonged life than a single cell since they can help one another through interchange of material. In this way there came into existence various kinds of lowly seaweeds. In the course of the geologic ages these became more and more complex in body structure, having stem and branches, internal conducting cells, spores for reproduction and holdfasts to anchor them to the

ground. With these rudimentary structures, the higher seaweeds were ready to spread from the marine waters to the lands, and probably by way of the marginal salt marshes and the river swamps. During this transmigration from the submerged and equable habitat of the sea to an ever changing one on the land, the holdfasts changed to absorbing roots, the conducting cells became the fibrous transportation system (wood), the stems and branches developed breathing pores, while the originally soft covering of the spores became tough so that they could withstand drought and dispersal by the winds.

Plants now live in all lands, not only on the continents but on the oceanic islands as well. This, however, seems not to have always been the case, since no land plants as fossils are known back of the Ordovician, although earlier softer ones may have merely failed of preservation. Toward the close of the Silurian, land plants became abundant, and in the earliest Devonian the best known forms (*Rhynia* and *Hornea*) have about the same organization as the living mosses, that is, are nothing more than rootless and leafless branching and duct-bearing stems not over 8 inches tall, covered with scattering breathing pores and specialized tips in which the reproductive spores are developed. These oldest known land plants are therefore more primitive in organization than ferns or rushes, but are structurally higher than seaweeds in having air-breathing pores. Now the question arises, how long before the late Silurian did these lowly plants appear? With them are associated still higher land plants suggestive of the club-mosses, so it is plain that the passage of certain of the more complex seaweeds to the lands must have taken place long before the Silurian. How

long before, we do not know, and yet it is possible that the transmigration from the sea across the strand or up the rivers may have taken place even as early as Proterozoic time. That the rivers had an abundance of plant food as early as the middle of the Ordovician is attested by the many small river fishes found in rocks of that age in Colorado and Wyoming. Although we cannot tell when the migration took place, many paleontologists are of the opinion that the lands of Cambrian time had, at least in places, lowly organized air-breathing plants.

ONE OF THE OLDEST KNOWN LAND PLANTS

Rhynia, found in the Lower Devonian of Scotland. These were merely branching stems, topped with spore cases, devoid of roots and leaves, and not over 8 inches tall. After Kidston and Lang.

TREES OF THE ANCIENT COAL FORESTS

Left, *Lepidodendron,* the scale tree, so called from the scale-like look of the leaf-scars. Center and right, *Cordaites,* associated trees related to the cone-bearing evergreens of to-day.

By the middle of the Devonian period, fossil plants were common and varied, and we can say that there were land floras. They were, however, of types rather unfamiliar to us, though resembling in a general way our rushes, ferns, and club-mosses. There were also fern-like trees, tall ground pines, and primitive evergreens with woody trunks nearly 2 feet in diameter and a height of 30 feet or more. This flora continued to increase and to become more varied until in the Pennsylvanian period it had upward of three thousand known species, luxuriant in development, and of world-wide distribution under a warm and equable climate.

The ancient ferns were then in their heyday. Some were delicate, others hardy or climbing, while many grew

THE DEVONIAN FOREST AT GILBOA, NEW YORK

The remains of this old forest were discovered during construction work for the Catskill reservoir. The trees are the oldest known seed-ferns, and have consequently been named *Eospermatopteris*, from Greek words meaning *dawn-of-the-seed-fern*. Restoration in the New York State Museum at Albany.

into trees. Club-mosses were also at their climax, and here again some reached the stature of huge trees. The most conspicuous forms were, however, the strange scale and seal trees, so named from the shape of the scars left by the leaf bases on the trunks and branches. *Lepidodendron,* the scale tree, which often reached a height of 100 feet and a diameter of 3 feet, differed from modern trees in that the trunk and many of the branches divided into two forks rather regularly. The leaves were needle-like, and many of the branches ended in long cones. *Sigillaria,* the seal tree, was unlike *Lepidodendron* in being rarely branched, and in bearing erect grass-like leaves toward the top only. They were not stiff trees,

TREES OF THE ANCIENT COAL FORESTS

Left, *Sigillaria,* known as the seal tree, from the impressions of the leaf bases. Right, one of the ancient rushes, *Calamites,* not unlike modern ones in appearance but often growing to diameters of a foot and heights of over 30 feet.

but were swayed much by the winds, and neither of them has living representatives.

Almost everywhere in the living world occur small rushes, usually less than 18 inches tall. The Pennsylvanian floras had a great abundance of these, but of ancient types, which were again of great size, the largest of them, the calamites, growing in thickets to a height of 60 feet.

Aside from their appearance and size, these early plants differed at once from most modern ones in their method of reproduction. Fertilization was not yet accomplished through the aid of honey- and pollen-eating insects, but in the main by the rains and winds. The reproductive agents were not the seeds with which we are so familiar, but were spores, simple minute germs often contained in great numbers in the cones. Moreover, sexed generation did not succeed sexed generation as in modern types which produce seeds, but there was an intermediate sexed stage, bearing the spores, which in turn gave rise to sexless plants; in other words, there was an alternation of generations.

As early as the middle Devonian, but especially in the Pennsylvanian, we also find the most primitive of seed plants, the seed-ferns, in some of which the seeds were as large as ducks' eggs. The presence of seeds was a great forward step in the evolution of the plant world, since in them the germ has developed into an embryo surrounded by much food—a method of reproducing that was to become the dominant feature of later floras. Other common seed plants were the cordaites, an extinct group of forest trees as large as the more common kinds of evergreens to-day, and having characters in common with the

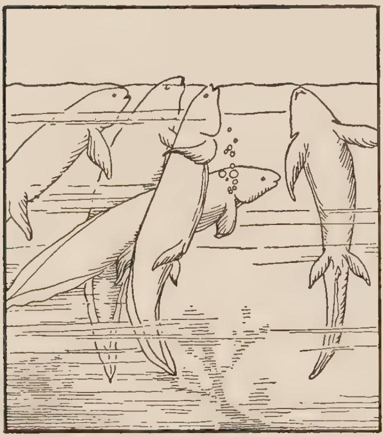
modern evergreens and maidenhair trees. All had simple strap-like leaves, sometimes a yard long, but none had needles like the cone-bearers; these came with the Permian.

Interesting as are all these early plants in indicating the advance of vegetation on the lands, certain of them have an added significance in being the source of one of our greatest stores of natural wealth. Under the even climate of the Pennsylvanian, and with the seas oscillating markedly over the low lands, great areas went over into fresh-water swamps, and in these flourished a luxuriant flora such as we now know only in the tropics (see figure, page 86). It was of quick growth, liberating spores in enormous quantities, and in time the swamps became filled with decaying vegetation, which with long time and the accumulating rock pressure from above was transformed into the several varieties of coal. These accumulations of coal are now found from Nova Scotia to Alabama, and from eastern Pennsylvania to Iowa, Kansas, Oklahoma, and Texas. There is no other supply of coal so great as this which was stored up in the rocks during Pennsylvanian time.

During middle Permian time, the world underwent one of its coldest intervals, which eventually blotted out most of the ancient floras. A change began to appear late in Pennsylvanian time, when the atmosphere became drier, though seemingly not colder, and deserts came into existence in most of the continents. As a result of these great climatic changes, the late Permian and the early Triassic were the times when out of the older plant assemblages developed the typical floras of medieval time, the progenitors of our modern ones.

CHAPTER XXV

THE EXODUS OF THE ANIMALS FROM SEA TO LAND



LUNG-FISHES

WHEN the lands were once clothed with the vegetation necessary for a food supply, the stage was set for their invasion by the animals that had hitherto been restricted to living in the sea. The transition from sea to terra firma might in some instances have been made directly across the strand, but it could in all probability have been accomplished more easily by way of the rivers and coastal marshes, and thence, through gradual adaptation, to the dry lands themselves. In this way, therefore, and at different times, we may imagine that there came out upon the lands stocks of marine animals that became earthworms, snails, thousand-legs, scorpions, spiders, ticks, insects, sowbugs, crawfish, and land crabs. There were, however, entire classes of animals that were never able to make this migration and accommodate themselves to the rivers, as, for example,

the corals, echinoderms, brachiopods, and cephalopods, which have always remained denizens of the salt waters.

Why certain of these marine invertebrates forsook their comfortable oceanic homes for the more strenuous life of the lands, while others remained in the marine realm, is a somewhat difficult question. The answer may lie in their different degrees of activity, as expressed in their mode of living: whether they went out in search of food, or, like Micawber, waited for something to turn up. Brachiopods and corals, for instance, pass their lives attached to some object, depending for a livelihood upon the food brought to them by chance currents. The molluscan phylum varies in this respect, some of the lamellibranchs, such as the clams, finding their way into fresh waters, and many of the snails coming out upon the land and multiplying exceedingly. The cephalopods, on the other hand, although they have become the most aggressive of all invertebrates, have nevertheless lacked the ability to live out of their native salt waters. The habit of actively searching for food seems to have begun in the most primitive coral-like animals, then to have been passed on to the worms and annelids, and from the latter along two independent lines, terminating in the arthropods and the vertebrates, respectively, the dominant land groups in nature to-day (see figure, page 235). The former, which include the insects, lead in numbers, but what the vertebrates lack in variety they make up in size and mentality. The diversification between the two groups may have been due to the two highly varied types of mouth, since that in the arthropods is a mill of many but weak jaws with no particular attacking strength, thus restricting them to feeding on small organisms and dwarf-

ing their size, while the vertebrate mouth is a powerful two-jawed toothed device that has a strong musculature for the biting and holding of prey.

Whatever the reason for the change of habitat, in the Silurian we find the scorpions as the earliest air-breathers, followed soon afterward in the Devonian by the spiders, ticks, and thousand-legs. When the earthworms came

EARLY TYPES OF LAND VERTEBRATES

Left, a thousand-leg (*Acantherpestes*); center, one of the big-bodied "dawn" spiders (*Eophrynus*); right, a scorpion (*Eoscorpius*). All of Coal Measures time. After Behm.

into being is not known, but possibly as early as the earliest land plants. Lamellibranchs were in the fresh waters as early as the late Devonian and tree-living snails appeared in the Pennsylvanian. All these creatures were invertebrates, but among the vertebrates fresh-water lung-fishes were already plentiful in the early Devonian, and their land-living descendants, the amphibians, were fully developed at least as soon as the end of this period.

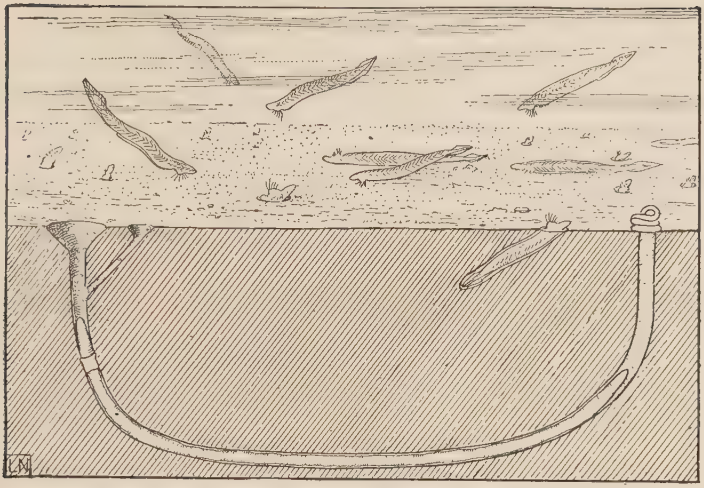
The insects, on the other hand, are not known until the Pennsylvanian. We may therefore say that since early in the last-named period the lands have been abundantly peopled with animals, with and without backbones, and in great diversity of form and organization.

Probably no marine animal can be shifted in a few hours from salt to fresh water, and continue to live. In the laboratory the shift can be made only after months of diluting sea-water into fresh, but no creature will live when taken suddenly out of either medium and placed in the aërial habitat. Among the many classes of invertebrates only here and there in nature to-day can a species change even gradually from a normal marine habitat to much freshened sea-water, but in these isolated cases lies the possibility of their habituating themselves to the rivers and fresh-water swamps. The difficulty lies mainly in the obtaining of oxygen from the air or from fresh water by means of organs adapted to taking it out of salt water. To meet this new condition, old organic structures have to be modified or wholly new ones developed; gills have to be changed into lung-books or tracheæ, as happened in the insects and spiders, or a part of the throat made into a rudimentary lung, as was done by the air-gulping lung-fishes.

It is likely that no animal ever voluntarily passed directly from the water habitat to that of the dry land, even though many kinds of invertebrates belonging to the amphibious region between high and low tide can live out of water for one or more days. The arthropods can do it more easily than any other tribe, since their gills are more easily modified or can be kept wet so as to take the oxygen directly out of the air. Hence it is in this phylum

that the transition is most often made. With the fishes the change never came voluntarily, but was forced upon them by the drying away of their water homes under arid climates.

Of all the animals that succeeded in surviving the transition from sea to land, it is the fishes that interest us most, since they are the first members of the great group of backboned animals to which we ourselves belong. Their origin has been the subject of much speculation, but it is generally agreed that the types from which they came may have been similar to two very ancient relics that are still living to-day; the first of these is the small, gilled, fish-like lancelet found in the sand of most shallow seas, and sometimes spoken of as "the prophecy of a fish," and the second the worm-like but gill-breathing marine form known as *Balanoglossus,* which has the necessary internal organization to develop backbones and other structures such as are present in the lancelets. The lancelets of the ancient seas are thought to have voluntarily spread into the rivers after they had become peopled with plants and small invertebrates, and, feeding upon these, to have gradually developed into tiny sharks, the so-called acanthodians. When and where this change was made is unknown. Fishes are present, however, in Ordovician strata (ostracoderms) and acanthodians in those of the late Silurian, while what seems to be a fish scale has recently come to light in Cambrian rocks from Vermont. But the rivers are continuous habitats only in wet climates; in semiarid regions they often dry away and so destroy all of their life excepting that which develops some method of tiding itself over the dry spell. In such evanescent waters the acanthodians are believed



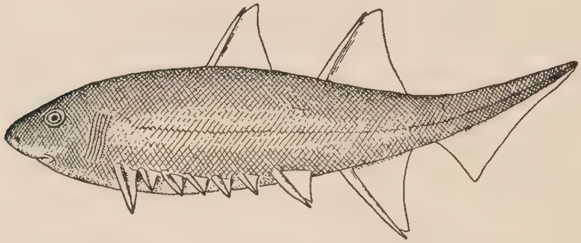
TWO VERY ANCIENT ANIMAL TYPES STILL LIVING TO-DAY

Such types were probably ancestral to the fishes, since they show the beginnings of a spinal cord and of gill-breathing. *Amphioxus*, the wriggling lancelet, prophetic of the fishes, is shown mainly above the sea bottom. Buried in the sand on the sea bottom is the still more primitive and worm-like *Balanoglossus*.

to have learned, previous to the Silurian, how to live through the dry seasons by burrowing in wet sands and gulping in air.

In order to be able to live out of water, and to survive periods of drought, it became necessary for the earliest fishes to develop a means of breathing air, since their normal breathing organs, the gills, are adapted for extracting oxygen from the water but not for taking it directly from the atmosphere. This they did by a modification, not of the gills, but of a part of the throat, which in most fishes is now changed into an air bladder used as a balancing organ. The highly varied structural range

of the air bladder in living fishes shows it to be of extremely ancient origin, and its ancestral condition is possibly shown by a pair of pouch-like outgrowths of the pharynx, or throat cavity, in the sharks. Stagnation of the water with a loss of its free oxygen would bring the fishes to the surface to gulp down air, and such pouches, if supplied with blood-vessels, would serve in a rudimentary way to aid in aërating the blood. A premium placed by the environment upon such structures would, it is thought, stimulate their development to the condition seen in the modern lung-fishes.



CLIMATIUS, AN ANCIENT ACANTHODIAN SHARK

The acanthodians were the most primitive of true fishes, ancestral to all the higher vertebrates. After Woodward.

In semiarid climates the struggle for existence in the evanescent waters is severe, not only because of the abnormal crowding of the individuals into constantly diminishing water-holes, and the reduction in the amount of available food, but even more so because of the increasingly saline and bitter character of the water. It is thought that under the stimulus of these changes, the surviving gill-breathing fishes first adapted themselves to burrowing in the sand. Thus protected in water and mud-

holes, there was for a time moisture to pass over the gills, but under such environments life was also very precarious and in the struggle most of the individuals were destroyed. However, after age-long failures in their efforts to gulp the air, the pharynx was gradually developed and perfected, the first known air-breathing fishes, the ganoids and lung-fishes, appearing in early Devonian time.

The air-breathing lung-fishes also learned to hobble about on their fins in search of new and more lasting water-holes, and so their fins became gradually more and more modified into legs like those of amphibians or frogs. Despite this newly acquired locomotor ability, however, it was only in the waters that they could lay their eggs and successfully rear their young, and this characteristic persists in the next higher group to which they gave rise, namely, the amphibians. Nearly all amphibians lay their fish-like eggs in the water, there to be developed, and it is this transformation, as seen in living forms, that reveals a most wonderful story of little fish-like gill-breathing young that gradually change into lung-breathing four-legged adults.

The first four-legged vertebrates, the ancient amphibians, appeared in the late Devonian and were common in the Pennsylvanian and Permian. These primitive forms were, however, very different from the living ones in that they went clad in the armor of their fish forebears. Their brain cases were covered by thick bones originating in the skin, and this head armature had holes in which were located the pairs of eyes and nostrils; and, remarkable as it may seem, the top of the head also had a small hole in which was situated a third eye known as the pineal eye. Such an opening is likewise found in

A TRIO OF EARLY AMPHIBIANS

In the left foreground is the tiny *Eumicrerpeton,* skeletons of which occur only in the clay nodules at Mazon Creek, Illinois. The unwieldy fellow in the rear is *Cacops,* found in the "bone beds" for which the Texas Permian is famous. The tadpole-like creature in the center is *Diplocaulus.*

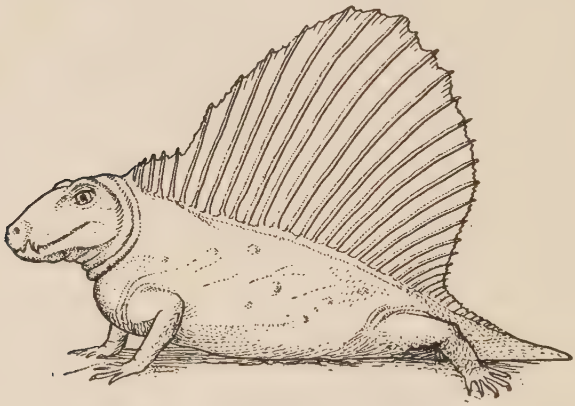
many fossil and some living reptiles, and the organ it contains is a vestigial one, whose ancestry can be traced back at least to Devonian time. And even this is not all, since the rudiments of this eye are present in the brain of all living vertebrates, including man!

The amphibian fauna of the coal swamps of the Pennsylvanian was a highly varied group of land animals, ranging in size from the 2 inch long *Eumicrerpeton* to *Eryops* with the length of an adult Florida alligator. Most of them, however, were small creatures resembling the living mud-puppies and salamanders. They were

sluggish animals, living mainly in the water. *Eryops*, which is one of the best known representatives, looked like a huge tadpole with its wide flat head and body, its short legs, and its flattened tail; it might well, as Huxley says, have "pottered with much belly and little leg, like Falstaff in his old age, among the coal forests."

We have seen that not only the fishes, but the amphibians as well, lay their eggs in fresh waters and give them no further parental attention. This necessarily restricts them to dwelling places within reach of water, and only the male of the midwife toad rears the eggs buried in the skin of his back. Hence before the broader reaches of the dry lands could be peopled by vertebrates, a new method of egg production had to be evolved, and here we find the most important and fundamental difference between the fishes and amphibians on the one hand, and the reptiles, birds, and mammals on the other. The next higher group above the amphibia, the reptiles, solved the problem by producing eggs containing within the shell not only the embryo but a considerable amount of nutritive material (yolk) for it to feed upon, and, in addition, a special organ to supply the embryo with oxygen taken from the air through the shell. These eggs for the most part were laid in the sand and left there to develop under the heat of the sun, thus doing away with the transitional gill-breathing and water-living stage that occurs in the young amphibia. The birds lay eggs of a similar kind, but protect and warm them by brooding during the period of development. It was left to the highest group, the placental mammals, to take the next step, and retain the egg within the body during the period of gestation, bringing forth the young alive.

All of the living cold-blooded vertebrates other than the fishes and amphibia—the turtles and tortoises, lizards and snakes, alligators and crocodiles—belong to the class Reptilia. The word reptile means creeping and crawling, and has reference to an animal that goes on its belly like the snake or moves with difficulty on short sprawling legs, like the alligator. There are, however, many reptiles



DIMETRODON, A BIZARRE PERMIAN REPTILE

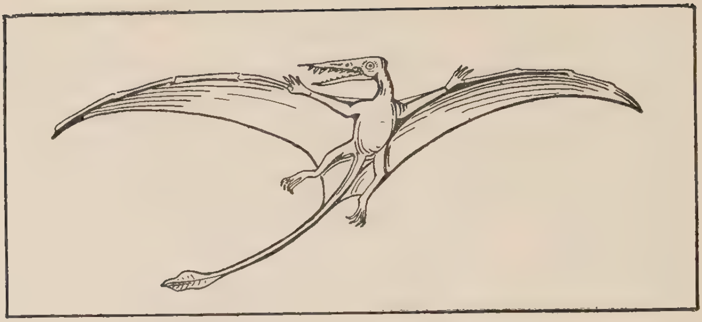
Such alert, predaceous land animals were developed in response to the increasing aridity of the time, which forced them to forsake the sluggish habits of their well-fed Pennsylvanian forebears. After Gilmore.

that are in no sense creeping and crawling animals, as, for instance, many of the fleet-footed lizards, certain of the medieval dinosaurs with their pillar-like legs, and the winged dragons.

Most of the Pennsylvanian and early Permian reptiles were plump, sluggish, more or less sprawling creatures basking on the land in the hot sun. In many ways they

still resembled their amphibian forebears, but had a marked tendency toward a reduction in the size of the skull and loss of armor. In all of them the feet terminated in five fingers or toes, and few appear to have been swift of foot.

Toward the end of the Pennsylvanian and during the Permian, however, the warm humid climate accompanying the widespread seas gave way to drier conditions as the lands once more emerged above the sea. This change of environment was reflected in the reptiles, which perforce became more sensitive and alert, developing into slender-limbed predatory types, more and more adapted to a carnivorous diet. Certain of them put on armor in the form of a high spiny crest along the back, as seen in *Dimetrodon,* the "giant spined reptile." Most of the late Paleozoic forms had large recurved holding teeth, and by the beginning of the Mesozoic these had begun to differentiate into the canines, incisors, and molars that are characteristic of their descendants, the mammals. Before these highest of organisms were to grow into their full racial stature, however, the reptiles were to dominate land and sea and air for the millions of years covered by the Mesozoic era.



THE EXTINCT FLYING REPTILE PTERANODON

CHAPTER XXVI

THE MESOZOIC ERA: AGE OF REPTILES

The great reptilian bubble swelled up and burst in the days of the Jurassic and Cretaceous periods, leaving behind a few crocodiles and lizards for to-day. . . . Out of the crash of the reptilian overgrowth and extravagances only the birds seem to have emerged with a promise still ahead. Our own stock, the line down which we have come, travelled clear of these excesses in development, and while the reptilian blood is in mankind, it is not that of the reptilian climaxes, the dinosaur or the brontosaur. It is the surest thing that the minorities of those ancient days saved the day for us.—John M. Clarke

PALEOZOIC time, starting with an organic world made up only of marine plants and invertebrates, witnessed the spread of their modified descendants into the fresh waters and thence out upon the lands, and their evolution in these new habitats into great and diversified floras, and into faunas that included the three lower classes of the vertebrate phylum—fishes, amphibians, and reptiles. At the end of the era, in the Permian period, we began to see foreshadowed the extraordinary flowering of the reptiles which was to reach its zenith in Mesozoic time, when they filled every habitat of the warm lands and all the seas, and eventually as veritable

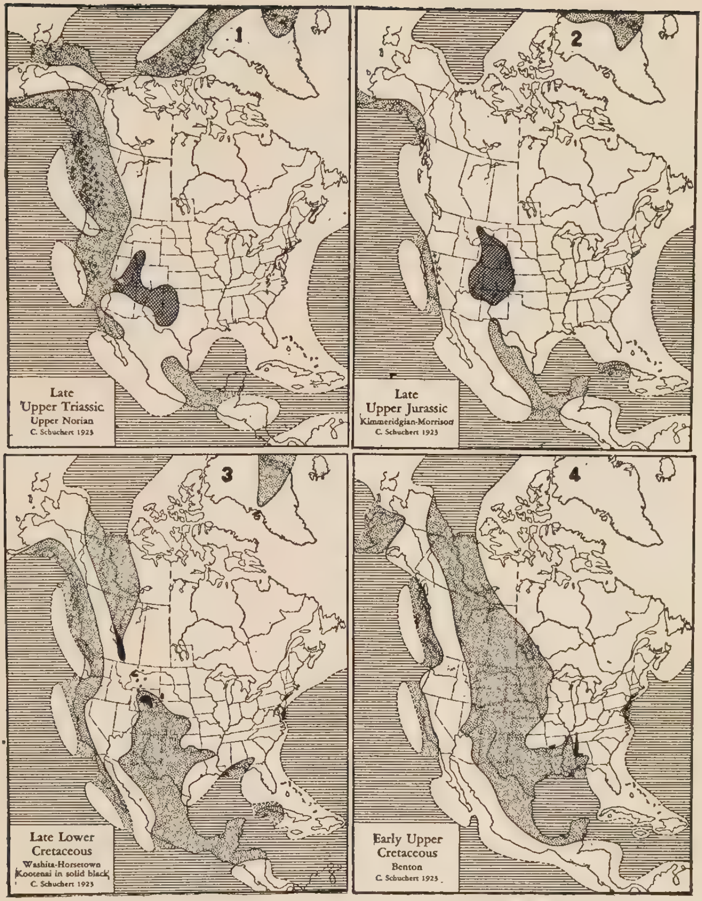
dragons possessed the air. Out of the early medieval reptiles came the more complex vertebrates, the birds and mammals, and these rose into ascendancy when the older and more primitive medieval floras gave way to the modern ones with their greater food values. Accordingly the organic world of Mesozoic time was intermediate or transitional between the ancient Paleozoic one and the dawning of the modern floras and faunas in the Cenozoic.

The Mesozoic era has but three periods, as contrasted with the seven of the Paleozoic, and together they endured but 11 per cent of geologic time. The first of these periods is the Triassic, a time mainly of land conditions, and one of preparation for the rising medieval kingdoms. During the succeeding Jurassic, the oceans once more flooded the lands widely, producing mild climates and easier life conditions. With the closing of the third period, the Cretaceous, came a time of great organic undoing, showing itself first in the dispossession of the medieval floras by the modern flowering plants, and then in the sounding of the death knell for all of the characteristic medieval animals of both the seas and lands, which passed, one stock after another, to make room for the modern types of marine invertebrates and for the ascending mammals that took possession of the lands early in Cenozoic time.

The emergent condition of the lands that prevailed during the close of the Paleozoic (Permian) held over into the early part of the Mesozoic, and it was only in the Pacific states that the Triassic seas spread over the continent. These western sea-ways, extending from California to Alaska, were studded with volcanic islands,

which poured out tremendous volumes of ash and lava. Apparently most of the lands were either desert or semi-arid, conditions that made for the development of agile reptiles and sparse floras. All of eastern North America was still highland, since the Appalachian Mountains made during the Permian had not yet been worn away. At the close of Triassic time there was, furthermore, uplift of the land all the way from Nova Scotia to South Carolina. This renewed highland area lay east of the Appalachian foldings, but nevertheless paralleled them closely. While the land was rising, it cracked deeply, letting down narrow but long tracts, and finally the entire region of the Connecticut Valley and the Piedmont Plateau from New Jersey south to Virginia began to settle and break up into numerous fault blocks, each tract having the blocks dropped and tilted in the same direction. As a result there were formed chains of block mountains very much like those of to-day in Arizona, Nevada, and California. These are the so-called Palisade Mountains, taking their name from the Palisades of the Hudson River. They are now gone, but the structure of the lands where they stood tells the geologist of their former presence.

Nor did the Atlantic Ocean flood the adjacent lands during the Jurassic period, but western North America was again transgressed by the Pacific and vastly more than during the Triassic. A final great flood came in from the Arctic, but did not persist very long, and its area in the United States eventually went over into great fresh-water swamps and lakes in which lived the dinosaurs, the largest animals that North America has ever had. Finally these swamps were blotted out as the western part of North America began to rise, markedly for the



MESOZOIC GEOGRAPHY

Volcanic areas along the Pacific at the end of the Triassic and Jurassic are marked by crosses. Cross ruling in the Triassic map indicates a desert area; that in the Jurassic map, the region where the largest dinosaurs are found (Morrison formation). Of particular interest is the great sweep of the Coloradoan (Benton) sea, North America's share of the world-wide floods of Upper Cretaceous time.

first time since the Proterozoic, into fold-mountains. This was the Nevadian Disturbance, which brought into existence the Pacific system of mountains, best seen in the Sierra Nevada, the Cascades, and the Coast Ranges of Canada. Between the Sierra Nevada and the Coast Ranges of California there developed a new geosyncline, the Californian sea, of which the present Great Valley of California is a remnant, while another trough appeared to the east of Queen Charlotte and Vancouver islands, known as the British Columbia geosyncline. Finally, the crust was invaded by deep-seated granites on an immense scale, and lavas poured out over the surface. With the rising of these magmas came the gold-bearing veins of quartz in the rocks of the Sierra Nevada, and the several kinds of ores in the Coast Ranges of British Columbia.

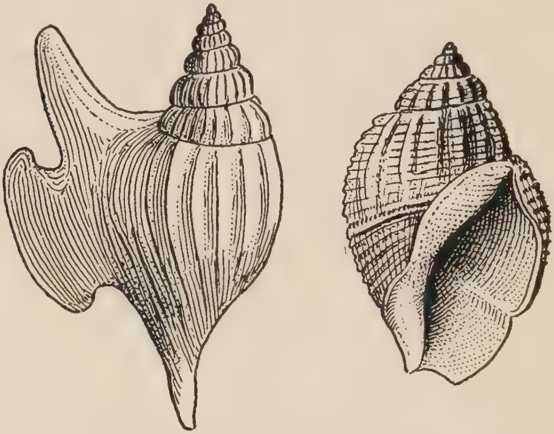
Tremendous eruptions of volcanic rocks also occurred during the Jurassic in eastern South America and in South Africa. These were prophetic of the downbreaking into the Atlantic of western Gondwana, a long-enduring land-bridge between Africa and Brazil: a foundering that was completed in middle Cretaceous time and thus put an end to the interchange of land life between the continents of the southern hemisphere.

With the Cretaceous, we come to the times that were to culminate in the making of the grand Rocky Mountain system. The Pacific system, as we have seen, originated during the close of the Jurassic, and about the same time the land to the east of these mountains was slowly bowing up into the great Cordilleran arch that extended from southernmost Mexico into Alaska. To the west of this arch were, as previously stated, the Cali-

fornia and British Columbia geosynclines, while to the eastward appeared a new sea, the vast Coloradoan flood of late Cretaceous time, stretching from the Gulf of Mexico into the Arctic Ocean. At the same time the Atlantic crept across what had always been the high borderland of North America from Massachusetts to Florida (Appalachis), while the Gulf of Mexico spread up the Mississippi Valley as far as southern Illinois. This was the greatest flooding of the continents in all geologic history. From time to time the Cordilleran arch continued to rise, and, with the many volcanoes that studded it, furnished nearly all the muds and sands that finally filled up the Coloradoan sea. Coal-making swamps then existed from southern British Columbia into New Mexico, and to-day these coal lands cover more than 100,000 square miles. Finally, because of pressure from the Pacific Ocean, the land began to fold throughout the area of the Coloradoan sea, marking the beginning of the vastly important Laramide Mountains, of which the Rockies are the most conspicuous ranges. The further folding of the Rocky Mountains was completed at the close of the Mesozoic era, but the great Cordilleran system received its present expression only after still another vast arching in late Cenozoic time.

While the Rocky Mountains were being folded, so also were the greater Andes, through their length of nearly five thousand miles. At the same time, or perhaps a little earlier, came the origin of the Indian Ocean through the downbreaking of the eastern end of Gondwana Land, and as a result of this great crustal unrest, Arabia and the region across to India were flooded by the Deccan basalts—the most colossal eruptions known to geologists.

With these great changes, the world climates became cool, and climatic zones in general were accentuated, but only locally in the mountains of Colorado and perhaps in central Australia is there record of glaciers. Nevertheless the drop in temperature was sufficient to change the floras of flowering plants, and there arose in the open plains more and more grasses and cereals. The Cretace-

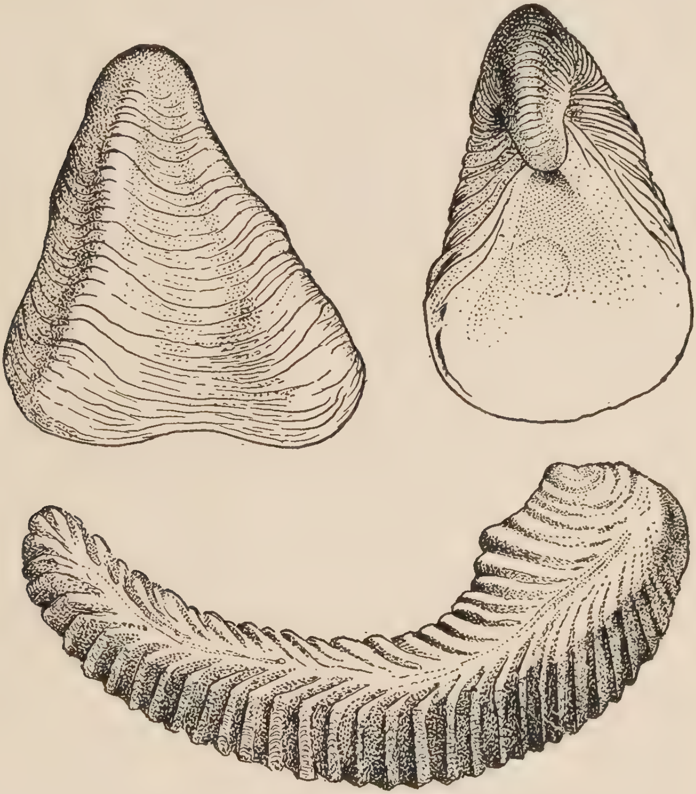


MESOZOIC MARINE GASTROPODS OR SNAILS
Left, *Aporrhais;* right, *Pseudoliva.*

ous inland swamps were now all blotted out, and with their disappearance and the changed floras, the highly specialized dinosaurs, dragons, toothed birds, and marine reptiles vanished. The medieval world was going rapidly, and the sun shone on the dawning of a new era, the Cenozoic.

The life of the Mesozoic differs markedly from that of the preceding Paleozoic. Following the dying out of

the Paleozoic marine life with the colder and more arid climates at the close of that era, it is among the corals, echinids, lobsters, and crabs, but chiefly among the mol-



TYPICAL OYSTERS OF LOWER CRETACEOUS TIME

Above, *Gryphea;* below, *Alectryonia.*

luscs, that we see the greatest amount of new life in the Mesozoic. The ancient corals died out with the Permian, but were replaced in the Triassic by modern types which

continued the ancestral habit of building great reefs wherever they found warm waters. The echinids, on the other hand, usually rare in the Paleozoic seas, found the medieval ones more to their liking and have increased in number and variety up to the present (see figure, page 237).

The Mesozoic seas, like those of the Paleozoic, were alive with molluscs, but in far greater variety than ever before. Many kinds of gastropods and bivalves were present in abundance, the oysters being particularly conspicuous after the Jurassic, but it was the cephalopods that were the most characteristic inhabitants of the medieval oceans. Among them were the highly varied and beautiful coiled shells known as ammonites, from a fancied resemblance to the horns of rams which are pictured as one of the attributes of the Egyptian deity Ammon. These chambered shells, arising in the Mississippian out of far simpler forms (goniatites), swarmed in the seas of Triassic time, but nearly died out toward the end of this period. Then in the Jurassic a new evolution took place among them, and out of a very small number of species thousands of new kinds came into being, one of which in the Cretaceous attained a diameter of 8 feet, with a coiled shell that, if straightened out, would be 30 feet in length. All through the Cretaceous, however, they declined in variety and died out completely with this period. Their going appears to have been due to the marine reptiles so common in all the warmer medieval seas, which fed not only on these shelled cephalopods but on the naked ones as well, the ancestors of modern squids and sepias. These naked forms, however, had a far greater distribution, living both

JURASSIC AMMONITES IN LIFE
After Fraas.

in warm and cold waters, and it was the cold-water forms that repeopled the seas of Cenozoic time. Their ancestors were the belemnites, which possessed an internal skeleton ending in a cigar-shaped guard, and hence derive their name from the Greek word *belemnon,* dart; in fact, these fossil "darts" were long regarded as the bolts hurled by Thor, the god of thunder. Some of these early squids must have been 3 to 4 feet long (see figure, page 305), but in the oceans of to-day there is one form which grows to a length of 55 feet (body 20 and arms 35). These giant squids are the most active of all molluscs, with the most specialized brain, and because of their decidedly predaceous natures have been called "pirates of the deep."

Lobsters appeared in the Triassic and crabs in the Jurassic, and the latter have ever since increased not only

in numbers but in variety as well. They are the scavengers of the seas, keeping the bottoms free of dead and dying organisms.

During the Mesozoic the ancient insects were modernized, and this seemingly before the flowering plants appeared. In the Jurassic lived not only cicadas, grasshoppers, locusts, and cockroaches, but flies, butterflies, wasps, and ants as well. The social ants were already present in the early part of this period; we are told by the foremost student of this interesting group, Professor W. M. Wheeler, that this colonial manner of living has originated independently in twenty-four different stocks of insects, and in the perfection of their organization for colonial life the insects are scarcely equaled even by man. In the communal life of ants we see the special development of the individuals into workers, breeders, warriors, and slaves, the farming of fungus, the storing of plants for food, and the keeping of other insects that give a kind of milk. It is only among these tiny animals, in fact, aside from man, that we see a sort of civilization—a living together of many thousands of individuals for the general welfare of the colony.

The most striking feature of Mesozoic life, however, was the dominance of the reptiles, which, from their humble beginning toward the end of the Paleozoic, increased in variety and numbers until they occupied in nature the place that the mammals hold to-day; surpassed it, in truth, since they were rulers not only of land and sea, but of the air as well. Before the close of the Triassic, the dinosaurs (to be described in the next chapter) were in possession of all the land habitats, and during this period or even a little earlier at least two

"TROUBLOUS TIMES FOR THE SMALL FRY IN THE OLD KANSAN SEAS"

Marine life of the Mesozoic, mainly reptilian. Upper left, pterodactyls; lower left, the mosasaur *Tylosaurus;* center foreground, an ichthyosaur with young; right background, a long-necked plesiosaur; at center, *Hesperornis,* the great diving bird; right center, a giant squid.

reptilian stocks went back to the seas and oceans. In order to make this change of habitat, walking legs and clawed feet had to be modified into long swimming paddles, but so well was this accomplished that certain of the Mesozoic marine reptiles reached a length of 50 feet, a size which implies an abundance of food and great agility in getting it.

First to forsake the lands for their ancestral oceans were the dolphin-like ichthyosaurs, or "fish-lizards," and the long-necked "near-lizards" or plesiosaurs. The ichthyosaurs, though not so well represented in this country as in Europe, are very well known to us because of their

fortunate entombment in Germany and England in shales that are easily cleaned away from them, so as sometimes to show even the texture of the skin. The earlier species moved about largely by the use of the four modified limbs, but the tail grew increasingly powerful until it came to be the almost exclusive means of propulsion.

The plesiosaurs were world-wide in their distribution. Carnivorous like the ichthyosaurs, the typical genus had a very small head, set at the end of a long snaky neck that was marked off distinctly from a box-like body. These strange creatures reached their culmination in the Cretaceous seas, the deposits of which in Kansas have preserved for us the remarkable *Elasmosaurus*, with a length of 50 feet, almost half of which was neck.

A third group of reptiles to become secondarily marine were the mosasaurs, which did not, however, find their way back to the oceans until late Cretaceous time. Their remains, again abundantly preserved in the Kansas chalk, sometimes show a length of 35 feet. They were apparently active swimmers, but differed from the ichthyosaurs and plesiosaurs in possessing a scaly armor, while their carnivorous habits were further aided by additional teeth borne on the roof of the mouth, and by an extra joint in the middle of each jawbone which allowed it to be curved outward, as in snakes, when the prey to be swallowed was larger than the normal gape of the mouth. All of these marine reptiles died out with Cretaceous time.

After the dinosaurs, the most extraordinary animals of the Mesozoic were the dragons of the air, known as pterodactyls. These highly carnivorous flying reptiles were more or less bird-like in appearance, and flew per-

THE OLDEST KNOWN BIRD, ARCHEOPTERYX

These birds show so many reptilian characters (tail, teeth, etc.) that if the feather impressions had not also been preserved they might not have been regarded as birds at all. Drawn from a restoration in color by Heilmann.

haps even better than the associated medieval birds. The largest ones had the extraordinary wing spread of 25 feet. The skeleton, however, was of very light construction, and it is probable that even the largest forms did not exceed 30 pounds in live weight; their bodies were, indeed, but an appendage to a huge pair of wings.

Probably the most striking single character of the pterodactyls was the elongation and modification of the front limbs into flying organs. This was especially true of the fourth or wing finger, which in the genus *Pteranodon* reached a length of 5 feet, and to which was attached the wing membrane, a very flexible leathery skin like that of bats. This feature is indicated in the name of the group, which comes from two Greek words meaning wing and finger.

Birds appear for the first time in the late Jurassic, and represent one of the most remarkable advances which the life of this period has to show. As yet but two kinds have been found, in the limestones of Solenhofen, Germany. One of these, about the size of a large pigeon, is called *Archeopteryx* ("ancient wing"). It has many points of resemblance to the reptiles, and many characters which recur only in the embryos of modern birds. The jaws were set with a row of small pointed teeth, showing the reptilian origin.

The oldest American birds come from the early Upper Cretaceous strata of Kansas. These are large reptilian water fowl of a species which has been called the "regal western bird" (*Hesperornis regalis*). They also are distinguished at once from modern birds by the possession of teeth. *Hesperornis*, a diver, stood about 4½ feet in height; its wings were rudimentary and of no use in air

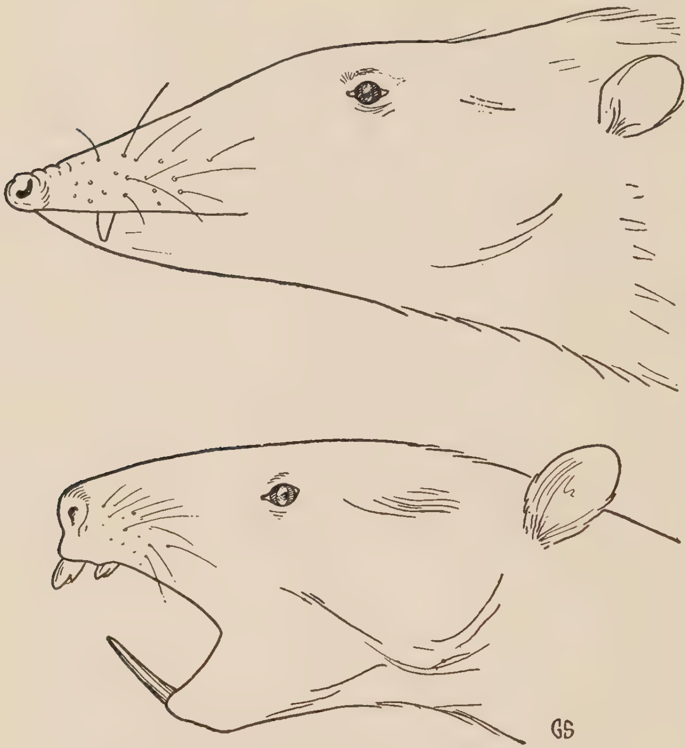
or water, but its great feet were webbed. Associated with this splendid type are found, very rarely, other small toothed birds with powerful wings (*Ichthyornis*, the "fish-bird"), which looked much like modern gulls and terns. All of these birds were fish-eaters.

The richness of the reptilian dynasties in the Mesozoic stamps it unmistakably as the Age of Reptiles, but all this magnificence was destined to pass, with almost incredible swiftness, when the lands came to feel the cumulative effect of the mighty Laramide Revolution. And with its

HEAD OF ARCHEOPTERYX SHOWING THE TEETH
After Heilmann.

waning, there emerge out of the obscurity in which they had been held by the reptilian dominance the advancing horde of the next great class of animals that were to inherit the earth, the Mammalia. Their origin was far antecedent to this time, probably reaching back to the late Permian, when they are thought to have developed out of the theriodont reptiles. Already in the Triassic we know them from rare and very tiny teeth and jaws found in Europe. At this stage they were egg-layers like their reptilian ancestors, and even to-day they have living

representatives in the echidna and platypus of Australasia. In the Jurassic, reptilian mammals, still known only from



HEADS OF TWO OF THE EARLIEST KNOWN MAMMALS

Above, *Zalambdalestes,* of the Cretaceous; below, the Jurassic *Ctenacodon.* Restorations by George G. Simpson. About 2½ times natural size.

jaws and teeth, were more common, and it was about this time that some of them became viviparous, giving birth to imperfectly developed young, as do the kangaroos. Dur-

ing the Cretaceous we do not again find mammalian records until toward the close of the period. By the very end of the Cretaceous, however, we know from further skeletal remains that there were at least six groups of these archaic mammals in existence, including insect-eaters, carnivores, ancestral monkeys or lemurs, rodents, and hoofed types. None were larger than sheep, the limbs were short, the tails long and heavy, and the brain exceedingly small. Most interesting of them all are the lemurs, as showing how far back in geologic history appears the primate stock to which man belongs. From this small "minority," once the reptilian menace was removed, and the earth clad with the grasses and cereals on which they could best feed, was to come a mammalian host that should exceed even that of the reptiles in variety, and that was to develop brain instead of brawn until it culminated in man.

Less spectacular than the remarkable reptilian development, but of even greater moment in evolutionary history —in fact, probably the most significant event in the life of medieval times—was the seemingly sudden appearance of the flowering plants in the middle Cretaceous, though straggling forms are known back at least to the middle Jurassic. The earlier Mesozoic floras (often spoken of as gymnospermous or naked-seed floras because the seeds are not in a closed seed-vessel but in one that is open and thus permits of direct fertilization without the intervention of style and stigma so characteristic of flowering plants) were fairly uniform in character from late Triassic time into the early Cretaceous, and the dominant groups were evergreens or conifers, cycads, represented by the sago palm of to-day, and maidenhair trees or

gingkos. There was also a great variety of ferns, but nearly all were of families different from those of the present day. Horsetails or rushes were common and much like living ones, but all of the calamites were absent. On the whole, the cycadeoids were the most interesting part of the Mesozoic floras, and it is thought that two out of every five land plants were then of this stock; in other words, the cycadeoids were as characteristic of the Mesozoic as were the dinosaurs. Among the conifers were the "big trees" or sequoias, along with cypresses and others.

The new flora of flowering plants, when it appeared, already had a very wide distribution and a great diversification, all of which means a long antecedent existence. Fruits, grasses, and cereals rapidly came into being, and these were of prime value in the ascendancy of insects, birds, and the archaic mammals. It was, indeed, the coming of these most interesting floras that made possible the present organic world, since without them there would have been no higher mammals, and therefore no man.

More than four-sevenths of the living floras consist of flowering plants (angiosperms, "covered-seed"), and they are adapted to all the environments in which land plants can grow. Their first great characteristic is that they alone, among plants now living, possess true flowers. "What is a flower?" says D. H. Scott, the English botanist. "In ordinary life our idea of a flower is associated with bright colour and often with a sweet scent. But we know that colour and scent are not there merely to give pleasure to us, but that they are of important service to the plant, by attracting the visits of insects. . . . The visits of insects (and in a few cases of other

CYCADS

Center, a living cycad. Right, trunk of a fossil form (*Cycadeoidea ingens*). Left, restoration, by Wieland and Dahlgren, of a cycad flower. Reproduced by courtesy of G. R. Wieland.

animals, such as humming birds) are chiefly of use to the plant, as Darwin showed, by bringing about cross fertilization between different flowers or different individuals. In other words, a typical flower is an organ of sexual reproduction, adapted to crossing by means of animal visitors, especially insects. . . . It is probable that the

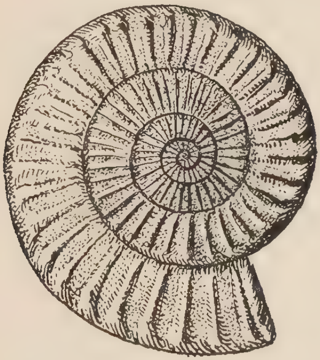
WIELANDIELLA, PERHAPS THE OLDEST KNOWN FLOWERING PLANT

From the upper Triassic of Sweden. This type is transitional between the gymnosperms and angiosperms, and in some respects closer to the magnolia stock than to the cycads. After Nathorst.

close relation to insect life has been the chief condition determining the evolution of angiosperms and giving them their supremacy among living vegetation."

When and where the flowering plants originated is still wholly unknown, and even now we may exclaim, as did Charles Darwin in 1879, that it is an "abominable

mystery." The most acceptable hypothesis in regard to the matter is that they arose in a stress climate, either arid or seasonally cold, perhaps as far back as the Permian, and out of cycad-like forms, or seed-bearing fernlike plants. Their homes for a long time thereafter are thought to have been in highlands with stress climates —of which the geologic record is the most incomplete —and it was probably not until middle Jurassic time that a few of them obtained a foothold on the lowlands near



ARIETITES, A JURASSIC AMMONITE

sea-level. Just what it was that made possible the very rapid dispersal of the flowering plants in the Jurassic and more so in the middle Cretaceous is also unknown, but it is permissible to point out the wide flooding of the continents in the later Jurassic, the planation of the mountains, and the introduction of world-wide warm climates, along with the appearance of bees and butterflies. In this connection we must not forget, however, that, as stated by Seward, another English student of

ancient plants, "the more efficient protection of the ovules, the germs which, after fertilization, become the seeds, the extraordinary variety in the floral mechanisms for assisting cross-pollination, the arrangements for nursing the embryo, and the structural features of the wood in relation both to rapid transport of water and to the storage of food, are factors which have probably contributed to the success of the angiosperms."

Whatever the cause of the rapid dispersal of the flowering plants, it is plain that with this quick spread the whole organic world of the lands began to be in a state of flux, changing into the one of modern times.

LORDLY TYRANNOSAURUS AND TRICERATOPS WITH THE ELIZABETHAN RUFF

After Osborn and Knight.

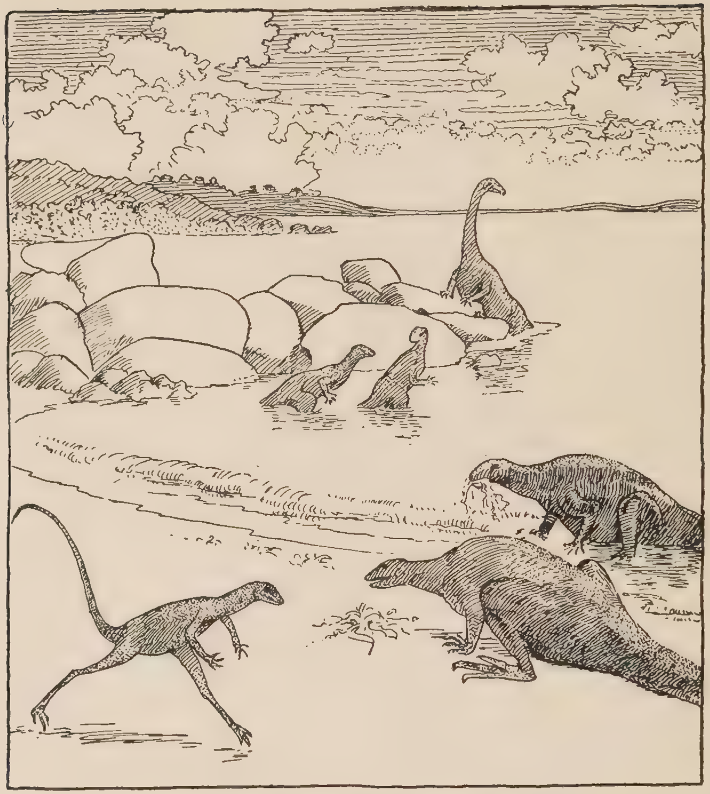
CHAPTER XXVII

THE MIGHTY DINOSAUR

THE lands of medieval time were so dominantly under the control of the "terrible reptiles" or dinosaurs that the era is usually referred to as the Age of Reptiles. During this era there lived on the lands and in the seas no fewer than eighteen great reptilian stocks, only five of which still survive. The dinosaurs, however, were the most significant, and it is only fitting that we should dwell on them at greater length.

Arising early in medieval time, the dinosaurs spread over all the lands, but are best known from their remains in North America, Africa, China, and Argentina. In their heyday they were the highest expression of life, both as to body structure and as to wisdom, yet the brain in the largest of them did not weigh more than 1 pound to 38 tons of flesh, while the average man has 3 pounds of brain to 150 pounds of body weight. In other words, the medieval world was characterized by brute strength and low mentality.

The dinosaurian career was not a short one, but lasted about fifty million years, three times as long as the



DINOSAURS BESIDE A TRIASSIC LAKE

In the left foreground is the small swift-running carnivore *Podokesaurus;* on the right, three representatives of the plant-feeding *Anomœpus* type; in the center, two smaller ones similar to *Nanosaurus* of Colorado. After Heilmann.

subsequent mammalian age, the dawning one of the present world; dinosaurs, says Professor Lull, "do not represent a futile attempt on the part of nature to people the world with creatures of insignificant moment, but are com-

parable in majestic rise, slow culmination, and dramatic fall to the greatest nations of antiquity." Nevertheless, out of them came no higher and rising dynasties.

The dinosaurs were the most extraordinary animals the world has ever seen, and as diversified in form and size as are the living mammals. Unlike these, but like most other reptiles, they reproduced through eggs, fossil examples of which have recently been found in Mongolia. They were superlatively low in brain power, and yet the nerve canal in the sacrum, that portion of the vertebral column which lies between the hips, was of startling dimensions, and shows that this part of the spinal cord from which the nerves went out to the great muscles of the hind limbs and tail was not less than twenty times the mass of the brain. As some one has said, the dinosaurs had more sense in their hips than they had in their heads! In any event, they had enough sense to eat when they were hungry, and anything more was superfluous.

One group of dinosaurs were great beasts of prey, with birdlike feet and eagle claws, running around on their hind legs after the fashion of ostriches. Their fore limbs were often absurdly small in proportion to those behind, and were used in catching, holding, and tearing prey. All of these forms were alert, rapid in gait, and carnivorous in diet. No fiercer biting head was ever evolved than that of the king-tyrant saurian, *Tyrannosaurus rex,* which lived in Montana and Wyoming. His Majesty had a length along the back of 47 feet, and for speed, ferocity, and bodily size was the "most destructive life engine ever evolved."

Associated with the carnivorous dinosaurs were other

bipedal forms, but of sluggish habits and with duck-billed muzzles, feeding on the vegetation of the swamps and water places. The hind legs of these bipedal dinosaurs were large and powerful, and on land furnished the essential means of locomotion. Their hands, however, were webbed, and served for paddles, and the long flattened tail was used to scull about in the water as do the alligators.

CARNIVOROUS DINOSAURS, TO SHOW THE SIZE RANGE

In the rear is the small *Anchisaurus* of the Connecticut Valley Trias, 5 to 8 feet in length; below, the 34-foot *Allosaurus* of the Jurassic of Wyoming. The latter are feeding on the skeleton of one of the contemporary plant-feeding dinosaurs.

Hugest of all the dinosaurs were the sauropods, giant vegetarians walking heavily on all fours, with more or less pillar-like legs, long snake-like necks, far-reaching tails, and a brain weighing less than a pound to govern a body with a weight of some 40 tons! The greatest of these was *Gigantosaurus* of East Africa, the largest land

animal known, with a length of about 80 feet, 36 of which was neck. His American ally, *Brontosaurus,* the "thunder saurian" of Wyoming, was about 65 feet in length, but relatively heavier in construction, weighing some 38 tons. Another native of Wyoming, *Diplodocus carnegiei,* "the

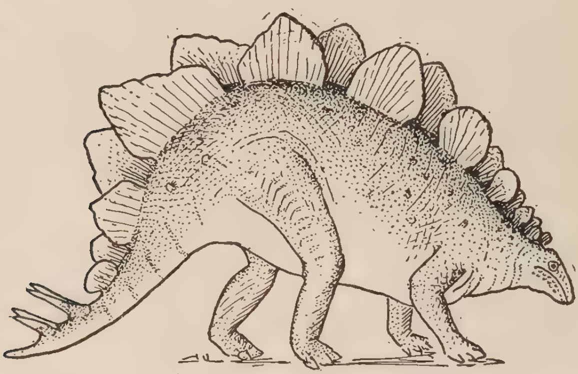
BRONTOSAURUS, THE "THUNDER SAURIAN"

A ponderous, sluggish reptile, about 65 feet long and weighing some 35 tons, probably spending most of its time in swamps rich in plant life, where the water would help to support its great weight. After Osborn and Knight.

animal that made paleontology famous," reached a length of 87 feet, but weighed less than *Brontosaurus* because of its slender build. These American sauropods are thought to have lived for the most part in swamps of river valleys in the area of the Great Plains before they were elevated to their present levels.

Most curious of all dinosaurs were the armored ones,

covered with plates and spines. These developed out of the duck-billed forms, and were a bizarre stock of heavy-limbed, small-headed, quadrupedal animals, browsing on leaves and twigs. Some attained 10 tons of flesh, and yet their brain weighed less than 3 ounces. Their homes appear to have been completely away from the water on the dry land, where they were subject to the attacks of their carnivorous colleagues; hence the need of a protective

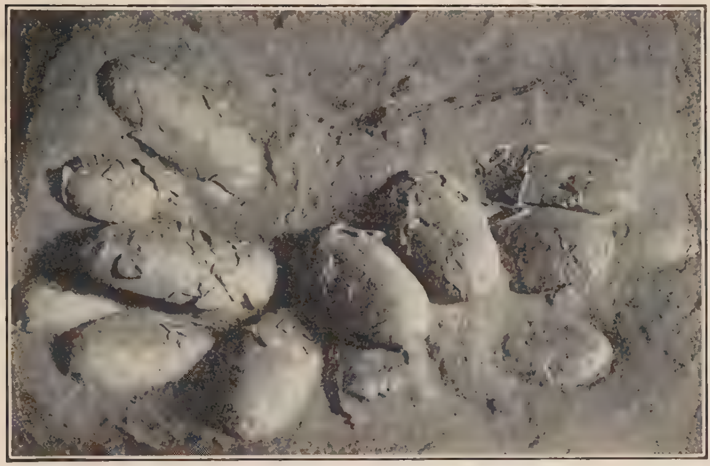


STEGOSAURUS, AN "ANIMATED CITADEL"
Note the armament and the small head. After Gilmore.

armor. One form, known as *Stegosaurus*, the "covered saurian," had, in addition to body armor, a row of large bony plates standing erect along the back, and a lashing tail near the end of which were two or more pairs of long sharp spines, making it a "huge battle mace." Such "animated citadels" must have been unassailable except by the fiercest of their flesh-eating kin.

Toward the close of the medieval era there appeared a very diversified horde of large-headed dinosaurs known

as ceratopsians, or horn-bearers, which are doubly interesting because of their varied evolution, chiefly with respect to the large head, which was used both aggressively and defensively. The skulls were wide and long, being drawn out backward over the neck into a prominent protective



DINOSAUR EGGS

Nest of fossilized eggs belonging to the dinosaur *Protoceratops*, found in the Gobi Desert by the Mongolian Expedition of the American Museum of Natural History, which has kindly supplied the photograph.

frill, usually 4 to 6 feet long but exceeding 8 feet in *Torosaurus*. Even with such great heads, however, the brain did not exceed 2 pounds in weight. The early forms had a dominant nasal horn, with a smaller one behind, but the nasal ones tended to reduce and those in front of the eyes to increase until we have *Triceratops* of the "three-horned face" (see figure, page 317), with a triple comple-

ment of horns to use in impaling an enemy. The Canadian *Styracosaurus,* on the other hand, had only one nasal horn, but the edge of its neck frill was frayed out into eight spikelike projections.

The great dinosaurian race reached its fullness of development in the late Jurassic and Cretaceous periods

DINOSAUR FOOTPRINTS

Slab of Triassic sandstone (12 × 4 feet) from the Connecticut Valley, still bearing the raindrop impressions made by a heavy shower some 75,000,000 years ago. Before the rain, the small dinosaur *Argoides* crossed the sand, and after it, a much larger one (*Steropoides*). Original in Peabody Museum, Yale University.

Most of the kinds persisted until toward the close of the Mesozoic era, but none of them survived the Laramide Revolution at its close. The disappearance of so strong and abundant a group presents an interesting problem, and has aroused much speculation. It is probable, however, that their death knell came with the obliteration of their homes in the swamps that bordered the inland seas, and with the reduction of the climate that resulted from the rising of the Laramide Mountains. No reptile with the dimensions and habits of a dinosaur could withstand

winters, even if they were no colder than those at present in the Dismal Swamp of Virginia. It is thought also that, vitally weakened and greatly reduced in numbers by the vanishing of their accustomed habitats and by the cooled climates, they were all the more easily assailed by the competing archaic mammals that began to rise into strength during late Mesozoic times, and it has been suggested that these more active and intelligent mammals fed in part on dinosaur eggs and on the young dinosaurs that never had parental care.

DENTAL BATTERY OF TYRANNOSAURUS, MOST FORMIDABLE OF DINOSAURS

After Osborn.

A PLEISTOCENE ASPHALT POOL WITH ITS VICTIMS

Rancho La Brea, near Los Angeles. American Museum mural, painted by Knight.

CHAPTER XXVIII

THE DAWNING OF THE PRESENT SCENERY AND LIFE: CENOZOIC TIME

OUT of the storm and stress of the Laramide Revolution the earth emerged into a new era, in which both the physical features of its surface and the life which moved among them were to become more and more familiar. This time of modernization, the Cenozoic era (from the Greek *cainos*, recent), had a duration of about 4 per cent of the earth's history, but even this small fraction means something like twenty million years. Moreover, what the Cenozoic lacks in time-length it makes up for in the dramatic advance of the mammals so long held in check by the great reptiles and the medieval floras, and their rapid evolution into group after group until they in turn reign undisputed over land and sea.

The oldest division of the Cenozoic era, the Eocene epoch, witnessed the dawning of the present life, as its name indicates (*eos*, dawn); it was followed by the Oligocene, Miocene, Pliocene, and Pleistocene epochs, so

called from the amount of recent life present in each, i.e., little of the recent, less of the recent, more of the recent, and most of the recent, respectively. The last of these divisions was the Great Ice Age, which lasted until the continental glaciers began their final melting off northern Europe and North America, seemingly something like 20,000 years ago.

In all of the older eras the oceans flooded the interior of North America more or less widely, but during the Cenozoic we have the beginning of the present marked emergence of the continent, the inundations being comparatively small marginal overlaps along the Atlantic and Gulf borders, and of an interior or geosynclinal nature only along the Pacific, and there in but a limited way. At no time during this era was more than 6 per cent of North America covered by marine waters, and the average was around 3 per cent. The most continuous and thickest successions of marine strata are in California, Oregon, and Washington.

With so much of the continent emergent, however, the lack of Cenozoic marine deposits is more than compensated for by the thick and widely dispersed accumulations of fresh-water and wind-blown deposits derived from the newly risen Rocky Mountains. As a rule, these are river flood-plain accumulations laid down under semi-arid and arid climates: sandstones, sandy shales, and local conglomerates. Volcanic ash in thick beds, derived from the volcanoes to the west that were active during the Laramide Revolution and later, and often reworked by water and wind, occurs, however, in most of the formations and indeed constitutes a considerable amount of the Cenozoic strata.

BADLANDS OF THE BIG HORN BASIN, WYOMING

X marks a

These rocks, carved into fantastic shapes by wind and water, are rich in fossil bones. Photograph by the American Museum of Natural History.

The rising of the Rockies did not at first affect the Great Plains to the east; hence the new streams, once they reached the foot of the mountains, still had hundreds of miles to travel at a low grade before they could reach either the Missouri or the Mississippi, and as a result, they overflowed their normal channels and built up great thicknesses of flood-plain deposits. Such flood-plain accumulations afford excellent conditions for the preserval of animal remains, and these particular beds, weathering out under the present arid climates into the picturesque "Badlands," have revealed the most interesting known record of mammalian evolution, the remains of one organic dynasty after another, whose histories have attracted the attention of paleontologists the world over.

The early stages of this history are found in the Eocene beds, which lie within the mountains in a series of basins that have furnished famous treasure trove to the "bone hunter": Bighorn, Wasatch, Bridger, and Wind River of Wyoming, Uinta of Utah, San Juan of New Mexico. As the mountains wore down and the Eocene basins were silted full, the Oligocene streams carried their burden farther east and laid it down in Wyoming, Montana, Colorado, Nebraska, and the Dakotas, while a small intermontane basin to the west—the John Day of Oregon—filled up with 3000 to 4000 feet of volcanic ash and buried a rich mammalian fauna. The Miocene deposits, with their wealth of mammalian remains, overlie those of the Oligocene and spread somewhat beyond them eastward, as well as southward into Texas; the Pliocene beds lie in regions scattered as widely as Oregon, Texas, and Kansas, but are of limited extent and often difficult to distinguish from those of the Upper Miocene.

The Mesozoic era, as we have seen, closed with the Laramide Revolution, when the Rocky Mountains were made the length of North America. The volcanoes associated with these mountains, however, continued to erupt throughout the Eocene and Oligocene, but the whole of the Cordilleran region otherwise remained practically unmoved until the Miocene. In the meantime the majesty of all the mountains was being worn away. Then a new revolution began, the Cascadian one, first in the middle Miocene in California, Oregon, and Washington, where mountains were rising accompanied by volcanic eruptions. At this time also originated the San Andreas earthquake rift of California, now 600 miles long, extending from north of San Francisco southeast into the Mohave desert, movement along which caused the great disaster of 1906. The high arching of the Cordillera, as a whole, however, did not begin until the Pliocene and apparently ceased early in the Pleistocene, during which time all of western North America was vertically elevated anywhere up to 7000 feet. The rumps of the Appalachians were also raised several hundred feet, and the whole of the Mississippi Valley went up from near sea-level to its present elevation.

The Cenozoic was therefore a time of extraordinary mountain making and continental elevation, and of downbreaking into the oceans on a vast scale. In Pliocene time, the whole of the Andes was also reëlevated from 3000 to 7000 feet, while in the late Miocene the long enduring land-bridge uniting Greenland to Norway and Scotland sank into the Norwegian sea. In Europe the whole Alpine system began to rise, but this movement ceased early in Pliocene time. The Himalayas, folded

for the first time in the middle Cretaceous, were folded again at the close of the Eocene, and still more decidedly toward the end of the middle Miocene. Finally in the Pliocene came the greatest elevation of all, which made these the loftiest mountains of the earth, and affected the land to the north for 1400 miles across Tibet into Mongolia.

The closing revolution of the Cenozoic era was again a critical period in the history of the earth, and as it culminated in the Pleistocene glacial climate, the conditions were all the more hazardous for the organisms that inhabited the arctic and north temperate regions. The warmer parts of the globe were the asylums from which the northern lands were again repeopled.

During the Laramide Revolution the climate of North America was reduced in temperature, and in early Eocene time it was cool and semiarid. Gradually conditions became milder and during the Oligocene there were world-wide genial climates. With the later Miocene and the rising of the lands in so many places, however, the climates again became cooler and drier, more or less desert conditions developing in the Cordilleran areas of North America, where they have prevailed ever since. Then in the Pleistocene came one of the most marked cold climates known to geologists, to be more fully discussed in Chapter XXX. We are now living in an exceptional time of rugged lands, obliteration of ancient plains, cooled climates, cold oceans, and marked temperature belts.

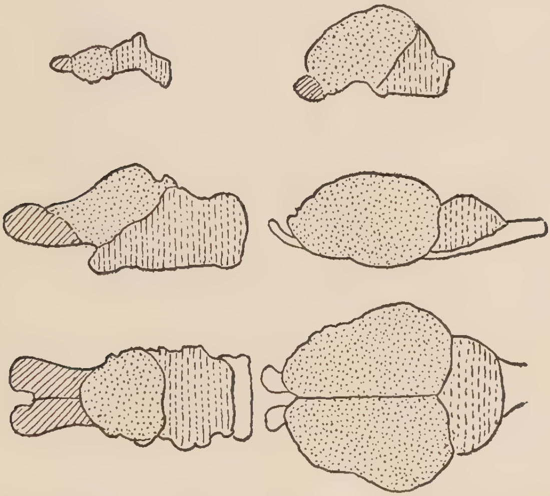
With the Cenozoic, the Age of Reptiles was succeeded by the Age of Mammals. Crowded into the background during the Mesozoic by the overpowering reptilian host, the tiny mammals had nevertheless managed to maintain

a humble existence, perhaps about on a par with the small rodents and insectivores of to-day, biding their time until the changing environmental conditions at the end of the Mesozoic brought disaster to the great reptilian dynasties.

Mammals differ from reptiles mainly in being warm-blooded animals, with milk glands for nourishing the young. Hair is as characteristic of them as feathers are of birds. The one feature, however, that gives them pre-eminence over all other animals is the brain, which reaches its greatest development in the mammalian stock. The brain of the higher vertebrates consists of two main parts, a lower and hinder division known as the cerebellum, and an upper part, the cerebrum, which is again divided into right and left hemispheres. In the Mesozoic mammals the brain was old-fashioned, generally small, but always relatively undeveloped in comparison with that of modernized mammals of equivalent bulk, especially in the upper brain or cerebrum wherein the intelligence lay. In the Eocene, the brain in most mammals began as a whole to enlarge, and here it was about one-eighth that of living forms of the same stocks, and this enlargement was by far most striking in the upper lobes. In the Oligocene, the upper brain increased rapidly in nearly all mammalian stocks until it finally was considerably greater than the cerebellum and almost covered it.

In the smallest modern gorilla the brain weighs 15 ounces and in the largest 20, while the weight of the entire body at maturity varies between 200 and 360 pounds, giving an average ratio of about 1 to 250. According to whether men are tall or short, their brains will be larger or smaller: the brains of Bismarck and Cuvier,

who were tall men, each weighed about 66 ounces, while that of the shorter Gambetta weighed about 42 ounces and that of Leibnitz less than 45. In adult men the weight of the brain varies between 65 and 34 ounces (average 49) and in women, due to their smaller size,

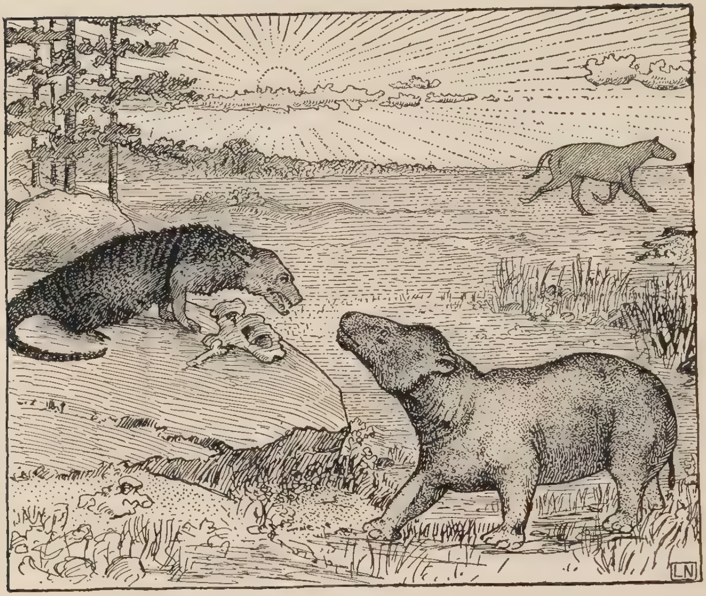


INCREASE IN SIZE OF BRAIN IN ANCIENT (LEFT) AND MODERN (RIGHT) MAMMALS OF SIMILAR SIZES

Top row: *Phenacodus,* Eocene; *Sus,* Miocene to Recent. Center row: *Uintatherium,* Eocene; *Hippopotamus,* Pliocene to Recent. Bottom row: Same, top view. Cerebrum (seat of intelligence), dotted. After Osborn.

it is between 56 and 31 ounces (average 44). When the brain is contrasted with the body weight, the ratio is about 1 to 45. Hence the Cenozoic was truly the time of transition from an ignorant world of brutes to the present Age of Reason, the Psychozoic era.

In North America, the Cenozoic opens with a most



EOCENE MAMMALS

Pictured together although their habitats were unlike. The large rhinoceros-like beast is *Coryphodon,* the wolfish one objecting to interruptions at mealtime is *Dromocyon,* and the creature wisely seeking diversion elsewhere is *Hyrachyus,* a small, primitive, running rhinoceros.

curious assemblage of native mammals, which were nevertheless greatly advanced over their Mesozoic forebears. Later in the Eocene there appeared in considerable numbers, both in western Europe and in this country, the progressive or modernized placental mammals, whose coming sounded the death knell of the archaic forms. Where they originated is not known, but it is established that there was free migration between North America, Europe, and Asia during the early Eocene and hence they are thought to have spread from some far northern

land. Among these early Eocene mammals were diminutive horse-like forms (*Eohippus*, see page 346), fleet-footed rhinoceroses, tapirs without a proboscis, the first ruminants and pig-like forms, squirrel-like rodents, carnivores, lemurs, and true monkeys. It was in the main the mammalian life of a mountainous country, superior in tooth and foot structure to its archaic ancestors, and of a higher intelligence.

With the spread of the grasses into the open plains of the Oligocene the animals began to take on a modern aspect and some of the living families can be traced back

CENOZOIC MAMMALS

In the right foreground, *Archeotherium*, a giant Oligocene pig; on the left, *Merycoidodon*, one of the oreodonts, an extinct stock that existed in great numbers; upper left, the Eocene *Notharctus*, an early primate.

to this time. Early in the epoch came a new mammalian invasion from Europe, and about this time the Old World lost its horses, but in North America there was continued evolution of the three-toed forms. The camels were also better represented and among them were grazers. Hoofed mammals were now present in bewildering variety. Rhinoceroses were common, as were also rodents like the beavers, squirrels, pocket gophers, mice, and hares. Among the ruminants, peccaries were numerous, the pig-like entelodonts grew to the size of a horse, and oreodonts, not unlike the peccaries and wild boars in appearance and size, ran in great herds. Here also is the final representative of the archaic flesh-eaters, *Hyænodon,* and among the modernized carnivores small dogs were remarkably abundant and diversified, more so in fact than ever before or since.

The Miocene was the "Mammalian Golden Age" and during the latter part of this epoch semiarid conditions were more prevalent and there were great grass plains. Accordingly many of the mammals changed from browsers to grazers, and horses, camels, and rhinoceroses were common and varied. A third tide of immigration brought from Asia by way of Alaska the first proboscideans to reach this continent, the four-tusked, long-faced mastodons (see figure, page 352), together with the cats and the first beavers. True deer appeared in the early Miocene and in addition there were slender and graceful deer-antelopes. Dogs were still present in great variety, and some of them were heavy and bear-like, *Dinocyon,* indeed, rivaling in size the great Kadiak bear of Alaska. There were also weasels, martens, otters, and raccoons.

The horses adapted themselves to all the different en-

vironments, ranging from the forest-loving *Hypohippus* of Oregon and Colorado through the grass-eating *Merychippus* to *Neohipparion* of the desert areas (see Chapter XXIX). The camels were both browsers and grazers, the former type producing the giraffe-like *Alticamelus*,

MIOCENE MAMMALS, REPRESENTATIVE OF TWO GREAT FAMILIES

Alticamelus, a camel blessed with the long neck and legs of a giraffe, allowing it to browse on the tops of trees far above the heads of its contemporaries; and the most ancient known American antelope, *Dromomeryx.*

which fed on the tops of trees. Small grazing camels ran in great herds and roamed over a vast expanse of country. Of rhinoceroses there were, in the early part of the epoch, the small diceratheres with their two horns placed side by side on the nose, and a hornless group (*Cœnopus*); in the

latter part, one of the most characteristic forms was a European migrant, the barrel-bodied, very short-legged *Teleoceras*.

Perhaps the strangest of all the Miocene mammals was *Moropus*, which looks as if it had been made up of odds

MOROPUS, A CONTRADICTION IN MAMMAL STRUCTURES

and ends from other groups: a horselike head, a long neck and fore limbs, the rear end of the body heavy and bear-like, and, most curious of all, the feet armed with the huge claws of a carnivore although the creature's teeth show it to have been a harmless vegetarian.

The mammalian history of Pliocene time was one of

continued variation. Early in the epoch there was still limited immigration from Asia, bringing in what is thought to have been an ape (*Hesperopithecus*), but otherwise the life of this time went without marked change into the Pleistocene. The Plio-Pleistocene was also the time of the greatest mammalian wandering, since the elephants, horses, and camels were then world-wide in their distribution. Then came the Great Ice Age and the ascendancy of man, and one after another the magnificent mammals vanished. To get a living picture of this mammal assemblage one must go to the table-lands of Africa, as did Roosevelt, who named the first chapter of his *African Game Trails* "A Railroad through the Pleistocene."

Because of the cold climate of Pleistocene time, there were two sets of mammals in North America, a northern one of low temperature, and a warm-climate one of the south. In the cold climate, the most interesting and widely distributed mammal was the Siberian woolly mammoth (page 353), standing about 9 feet at the shoulders, which came to America across the Alaskan bridge and ranged south through British Columbia into the United States and east to the Atlantic coast. It died out late in Pleistocene time. Another was the American mastodon, with a range very similar to that of the woolly mammoth; this great beast was most abundant in the forested regions and rarer in the plains country south of the ice, and persisted so long that it may have been hunted to extermination by the red men. The caribou and reindeer ranged south into Pennsylvania, and musk oxen into Utah, Arkansas, and Ohio. The stag-moose was a late arrival during the late Pleistocene.

In the warm climate of earlier Pleistocene time lived the great Columbian elephant (figure, page 342), 11 feet tall at the shoulders, and the even taller imperial elephant (figure, page 352), said to have reached 13½ feet in height. Horses were varied and exceedingly numerous, but all vanished before the close of the Pleistocene. Camels and llamas also were common, and bisons as well, one of which had a horn spread of 6 feet. The ground sloths, of South American origin, were present in two forms, one of them, *Megatherium,* being as large as a small elephant.

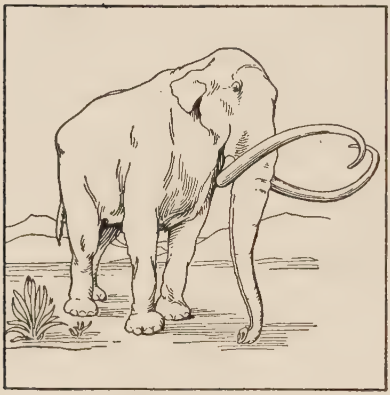
In geologic times, as to-day, the animals were wont to congregate in certain places where food, or more probably water, was to be had in abundance. When they were trapped in these places by flood or other disaster, the resulting graveyards become happy hunting grounds for the paleontologist. One such locality, the rich Agate Spring quarry in Nebraska, has given us a nearly complete picture of the larger mammals of this region in Oligocene time. Of even more interest, however, are the faunal revelations of the now famous asphalt pool at Rancho La Brea, near Los Angeles, which, by trapping the unwary animals venturing out upon its treacherous surface, held them to their undoing and our future enlightenment. To these tar pools, with their deceptive look of water, came birds in great variety—pelican, duck, geese, and condor. And for the same reason came the huge slow-moving ground sloths, the unwieldy mammoths, the young camels and horses and bison and deer. As they felt the tenacious grip of the sticky asphalt, their cries and struggles brought to the scene their natural enemies, the tigers, lions, and wolves, lured by the prospect of an easy kill but often themselves victims of the deadly tar. Bears there were,

and coyotes, but these were overshadowed by two of the most terrible carnivores of all times, *Canis dirus,* the "grim wolf of the tar pits," and his feline rival, *Smilodon,* the great saber-tooth tiger.

SMILODON, GREATEST OF SABER-TOOTH CATS

CHAPTER XXIX

EVOLUTION AMONG THE CENOZOIC MAMMALS: HORSES, TITANOTHERES, ELEPHANTS



COLUMBIAN ELEPHANT

IN demonstrating the truth of evolution, the horses, above all organisms, are the best illustrations of the working out of this doctrine: the "show animals" of evolution, with a known history running back through millions of years. Moreover, in historic times, their story is closely linked with that of our own race, since they are generally admitted to have been one of the greatest factors in the growth of our civilization. In our early history, the horse was used for food, and at Solutré, a prehistoric station in the department of Saône-et-Loire, France, there is a pile of horse bones estimated to represent a hundred thousand individuals. Later the horse became our chief means of travel and our beast of burden in agriculture and warfare; and in still more recent times, due somewhat to our use of selective breeding along evolutionary lines, various equine strains have furnished the perfect organic running machines whose contests crowd our race tracks.

As migrants into all continents, and in adapting themselves to varied environments, from torrid to arctic climes, horses have had but two equals, elephants and man. As W. D. Matthew says, the horse "is perhaps the finest example of what nature, acting through millions of years, has been able to accomplish in the way of adapting a large quadruped to speed over long distances, and likewise of the extent to which man, during the few thousand years that he has controlled its development, has been able to improve upon nature, in the sense of adapting it to serve more exactly his own purpose."

The horse family includes the living horses, zebras, and asses. These are characterized by very long and slender feet, each composed of but a single functional toe, the third digit. The hoof is the equivalent of the nail or claw of the third finger or toe in other animals; modern horses, therefore, walk upon the very tip of the third finger nail. As the third toe in each limb supports the entire horse, it is necessarily much larger than in animals in which the weight is distributed among several digits. There is, however, on either side of the functional digit, a slender element known as the "splint bone," and these are vestiges of the second and fourth toes of the original five in the ancestors of horses.

The teeth of horses are as peculiar to them as are their one-toed feet, and have reached their present state as a result of adaptation to the changing equine diet. The molars are long square prisms which grow up from the gums as fast as they wear off on the crowns, and the grinding surface exhibits a peculiar and complicated pattern of hard enamel, between which are softer spaces composed of materials known as dentine and cement. Both

the length of tooth and the complexity of pattern have been developed in response to the need for greater resistance to the wear of the silica in the hard grasses on which the horse has come to feed, and can be traced back through definite stages to the much shorter and comparatively simple-patterned teeth of the early members of the

PROGRESSIVE CHANGES IN THE TEETH OF HORSES
Modern horse on left, *Eohippus* on right. After Loomis.

race, whose food consisted of the softer forest vegetation.

The brain of living horses is large and richly convoluted, implying a high intelligence but not equal to that of the elephant. The docility of the horse and its ability to learn are notable, but, on the other hand, it is emotional, and its psychology is largely linked up with its normal mode of defense—flight. In the wild state, this

impulse toward flight is of the greatest possible aid as a means of survival.

Huxley many years ago said that the horse must have been derived from some quadruped which possessed five complete fingers or toes (called digits) on each foot and which had the bones of the forearm and of the lower leg complete and separate. Moreover, if the horse has thus been evolved, and the remains of the different stages of its evolution have been preserved, they ought to present us with a series of forms in which the number of digits becomes gradually reduced, the bones of the forearm and lower leg take on the equine condition, and the form and arrangement of the teeth successively approximate to those which obtain in existing horses. Since that time, nearly all of the missing links in the evolution of horses have been found, and nowhere is this history so complete as in the Cenozoic formations of the Great Plains of the United States.

The horse family has been traced back nearly to the beginning of the Cenozoic without a single important break. The line, so far as our knowledge goes, has its beginning in little animals no larger than our domestic cats, which have left their records in the early Eocene rocks of England. In some respects these little creatures, the hyracotheres, were not particularly horse-like, and they can be distinguished with difficulty from the ancestors of the tapirs and rhinoceroses that were living at the same time. They are known only from the skulls. The stock seems to have died out in Europe, however, and it is to our own country that we must look for its further continuation.

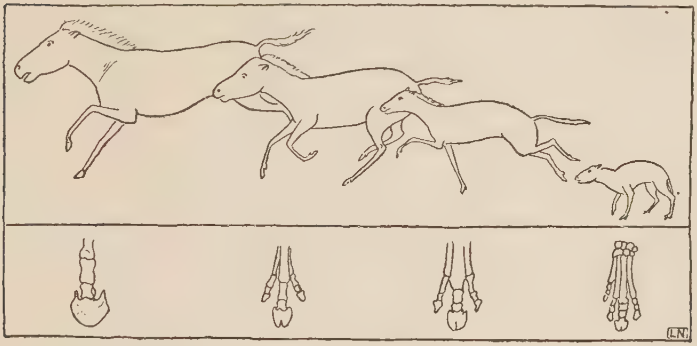
The first horses to appear in America were the little

"dawn horses" known as *Eohippus*, the remains of which occur in the early Eocene beds of Wyoming and New Mexico. They were graceful little creatures no larger than a fox terrier, about 11 inches tall at the withers. On the front feet they had four functional digits and the vestige of another, while the hind feet had three toes and two tiny splints, the vestiges of the first and fifth digits, thus showing clearly the five-toed ancestry. The molar teeth were cusped and short and of the browsing type; the neck was very short, the body long, with an arched back, the limbs and feet short, and the hind limbs much longer than the fore.

Eohippus was followed in the middle and late Eocene by *Orohippus* and *Epihippus*. The increase in size is slight, but *Orohippus* has lost the splint of the fifth digit on the hind foot. *Epihippus*, on the other hand, shows the beginning of a tendency that is to loom large in the race's later history, namely, the enlargement of the central toe to a size greater than that of those on either side.

Living in the forest, these little Eocene horses fell an easy prey to the carnivores of the time. With the coming of drier climates and the increase of grass lands (prairies) in the Oligocene, the horses therefore spread for protection into the open plains, and here they developed more and more speed. As a result of the elongation of the lower part of the limbs and the development of the sprinting habit of getting quickly up on the toes, came the gradual loss, through disuse, of the additional digits, and the necessity of providing greater resistance to the wear of the harder grasses brought about an equally remarkable change in teeth, from the browsing to the grazing type.

In the Oligocene, we find *Mesohippus*, the size of a



HORSE EVOLUTION

A frieze showing four stages in the evolution of the horse. Reading from right to left: *Eohippus, Mesohippus, Neohipparion, Equus.* Below, changes in the forefeet of the types shown directly above, beginning with four toes and ending with the single third toe.

coyote, and *Miohippus,* as large as a sheep. These two horses have three toes on each foot, and the middle toe is now much the largest. The teeth are low-crowned and of the browsing type, but changing toward those of a grazing animal.

The Miocene saw the more or less homogeneous original horse phylum begin to split up into several groups that were to evolve independently, some to carry the line onward into the horses of to-day; others, less adaptable, to finish their racial course and die out. In the middle part of the epoch the three-toed horses are still mostly browsers, though some of the progressive ones are changing rapidly toward grazers. It is here, therefore, that we find the intermediate *Merychippus,* in which the teeth show a transition from the older short-crowned type to those with long crowns, and the side toes no longer touch the ground. The ever-present conservatives are repre-

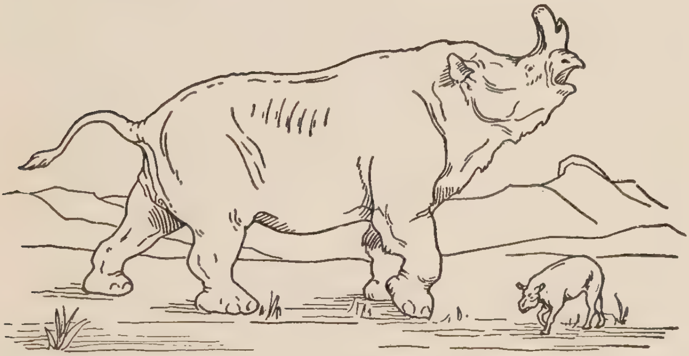
sented by *Hypohippus,* which, although it has increased in stature to the size of a small pony, has the wide flat hoof and strong side toes that fit it for soft ground, and teeth that are of the browsing type: in other words, a forest horse.

The latest stage in the three-toed horses is represented in the Miocene and Pliocene by *Hipparion,* with antelope proportions but with a very large head, and by *Protohippus* and *Pliohippus,* which approach more nearly the proportions of our modern types.

Beside the three-toed horses of the Pliocene we find the first one-toed horse, belonging to the genus *Equus,* which persists into our times. This genus in the earlier half of the Pleistocene had at least ten species, among them horses larger than any now living. The best known of these, though not the largest, is "Scott's horse" from Texas, which in proportions of head and neck, body and limbs, resembles Burchell's zebra found in Africa to-day.

During the Pleistocene, horses must have roamed in enormous herds over the Great Plains; their bones and teeth are, indeed, so abundant in certain formations that these are known as the Equus beds. Not only this, but at the end of the Cenozoic the broad land connection between Asia and North America made it possible for the horses to become cosmopolitan, and to occupy the plains in all the continents save Australia. This makes it all the more strange that the race should have become extinct in the early part of the period following the Pleistocene in both Americas and in Europe, surviving only in the horse and wild ass of Asia and the wild ass and zebra of Africa. Our present wild horses are descended from domesticated ones brought over by the Spanish explorers.

By way of contrast to the familiar horses, with their long evolution, we may glance at a group of strange animals whose history is limited to the Eocene and earliest Oligocene. These were the hoofed titanotheres, or "giant beasts." Appearing in the early Eocene in two already abundantly represented genera, *Lambdotherium,* a slender-footed running form of the size of a coyote, and the larger *Eotitanops,* slightly smaller than a full grown tapir,



FIRST AND LAST OF THE EXTINCT TITANOTHERES
Eotitanops and the large *Brontotherium.*

they came to be among the commonest of mammals, giving their name to the Titanotherium beds of the Oligocene, which Osborn calls "one of the grandest and most famous of mammal-bearing horizons." In the Middle Eocene, they diverge into broad-headed and long-faced types, both somewhat tapiroid in appearance, and here also they begin to develop horns on the forehead above the eyes. By Oligocene time they have diversified greatly, and become elephantine in proportions. Their most characteristic feature, however, is the horns, which have

shifted forward until they lie on the nose, and have attained great size. The skulls have grown very broad and massive, and the upper profile of the head deeply concave. *Brontops robustus,* the flower of this race, was doubtless an adversary whose charge would be feared as greatly as that of a rhinoceros to-day. Like that dull-witted beast, however, and even surpassing it in this respect, the titanothere's brain was "absurdly small," hardly of a size to contain a man's fist, and this lack of mentality was doubtless a factor in the quick extinction of the group in the early Oligocene, since they had no contemporaries among the carnivores formidable enough to give them battle.

Another great group of mammals whose evolution rivals that of the horses in interest, though not in importance to mankind, is the elephants. Like the horse and man, they have been world travelers, penetrating all the continents except insular Australia, and among present-day animals they still stand foremost in size, in strangeness of form, and in bulk of brain.

Elephant-like mammals are technically known as Proboscidea, the proboscis being the trunk which is their most characteristic feature. This is, in reality, the greatly elongated nose, nostrils, and upper lip, forming a very flexible and powerful muscular adjunct to the head, and serving many purposes, chief among them the gathering of food and water and the conveying of these to the mouth far above the ground. The trunk developed as a natural result of the shortening of the neck required by the increasing weight of the head with its great tusks, and when the lower jaw began to elongate to give support to the tusks while digging, the trunk was extended still

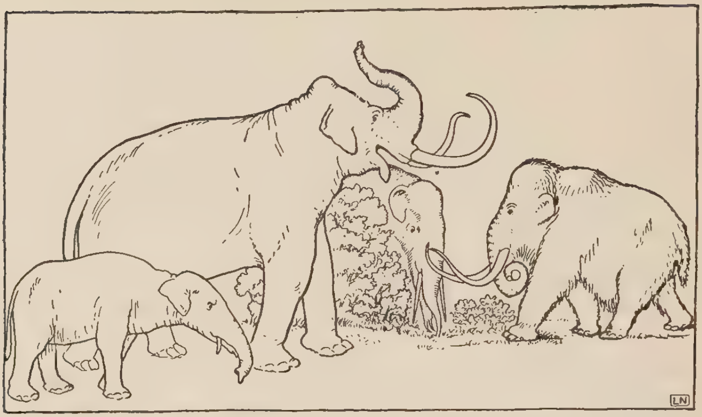
farther to reach beyond them. It did not, however, reach its greatest usefulness until the lower jaw, again shortening, left it pendant as in the living forms.

Because of the necessity for greater mechanical leverage, the development of the trunk brought about a shortening of the skull and a corresponding increase in height, giving to the elephant its "dignified, intellectual look." It was not, however, accompanied by a similar increase in brain, the enlargement of the skull being accomplished by the introduction of air cells within the bones, leaving the brain case the same size as before.

The general increase in weight led to a third marked proboscidean tendency, that toward the pillar-like limbs usually found in land animals of great size, which transmit the weight to the ground through a vertical shaft.

The oldest undoubted proboscideans are found in the early Oligocene of Egypt (*Paleomastodon*). They probably lived in streams and lakes, and it was not until the group took to the forests and grassy plains of Asia in the Miocene that their distribution became general. In the Pleistocene, the distribution of the elephants was nearly world-wide, and in all climates, from the tropics to the Arctic Ocean.

Paleomastodon was about the size of a tapir, with a narrow face and a well-developed, flexible snout rather than a trunk. The tusks of the skull were short, compressed, and outwardly directed; those of the jaws, while larger, pointed straight forward. These tusks originated in the second incisors, the other front teeth remaining small. All of the grinding teeth were in place and functioned at the same time, which is not true of the later proboscideans. *Paleomastodon* or its descendants, the



VARIOUS STAGES IN ELEPHANT EVOLUTION

Left to right: *Paleomastodon,* of the Oligocene of Egypt, the oldest undoubted proboscidean so far found; *Elephas imperator,* the Imperial Elephant of the Pliocene and Pleistocene, largest known member of the race; the long-faced, four-tusked *Trilophodon* of the Miocene; and the woolly mammoth of the Ice Age (*Elephas primigenius*). Mainly after Osborn and Knight.

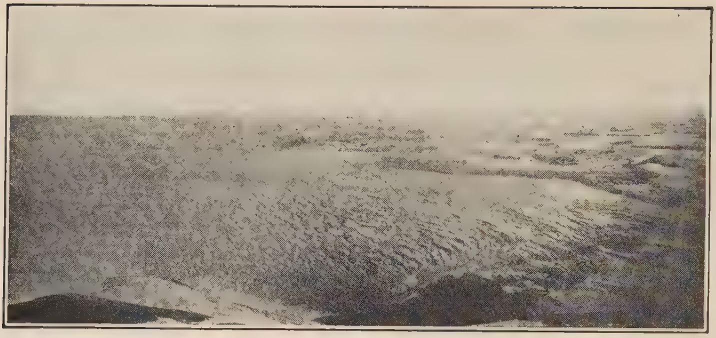
long-faced forms, crossed from Africa by way of a land-bridge across the Mediterranean from Tunis, Sicily, and Italy to Eurasia. This bridge was in existence in Oligocene time.

The Proboscidea early differentiated into two groups, mastodons and elephants, of similar appearance but with very different teeth. The mastodons, which reached America before the elephants, were sometimes two-tusked, as in *Dibelodon* of the Pliocene, and sometimes four-tusked, as in *Trilophodon* of the Miocene and in the later *Tetralophodon. Trilophodon* carried the elongation of the lower jaw to the greatest extent of any proboscidean, that of *Trilophodon lulli* reaching a length of 6 feet 7 inches. Their Pleistocene representative, in which the lower tusks

had been lost and the lower jaw consequently shortened, was the American mastodon, the best known of all our fossil proboscideans, whose remains are found from Florida north into Alaska, from Connecticut to California, and from central Russia eastward throughout Siberia.

Of true elephants, which include the living species, there were at least a dozen extinct kinds. Their evolution out of the ancestral mastodons probably took place in southern Asia, where occur remains of *Stegodon,* which is intermediate in tooth structure between the two groups. Succeeding this, Europe had in the Pliocene and early Pleistocene two immense species, *Elephas meridionalis* and *Elephas antiquus,* the former measuring 13 feet at the shoulder. The group culminated in the three American species of the Pleistocene, the imperial elephant (*E. imperator*), which was probably the largest of all the Proboscidea, slightly exceeding the stature of *E. meridionalis;* the Columbian elephant (*E. columbi*), which shows the maximum heightening of the skull to balance enormous tusks; and the woolly mammoth, *E. primigenius,* again with great tusks, sometimes exceeding 11 feet on the outer curve, and protected against the arctic cold by a coat of long hair.

There is excellent evidence that man was well acquainted with the woolly mammoth in western Europe, since toward the close of the Pleistocene he engraved its picture on bone and ivory and painted it on the walls of caves. America lacks evidence of this particular sort, but charcoal and potsherds found associated with elephant remains in various parts of the country seem to show that the earliest red men of this continent also knew the elephants.



Photograph by Drygalski.

ANTARCTIC ICE-CAP

CHAPTER XXX

THE GREAT ICE AGE

The influence of the Glacial Period on the history and development of the United States is easy to see "when one remembers that the manufacturing in New England developed first as a response to the water power, which is still utilized; that water power, similarly caused by glacial action, is extensively used at various points as far west as Minneapolis; that the Great Lakes Waterway is a product of glacial action; that the route of the Erie Canal was made possible by glacial lake deposit, and by glacial lake outflow into the Mohawk; that the level surface of the Central States, and the treelessness of the prairies which induced early and rapid settlement and development of agriculture, are due to glacial deposition. . . . Surely, had there been no recent glaciation, the industrial history of the United States would have been notably different, and it is very doubtful if its development would have been anywhere near so rapid as it has been, or if its history would have been even approximately what it has been.—R. S. Tarr.

IN the geologic history of the earth as we have seen it unfold, the part played by climate has been stressed at different places, but chiefly for its effect upon life. Very early in the story we learn of a widespread drop in temperature recorded in glacial deposits in such far separated regions as Ontario and Australia. The land life of the Permian had to meet the double menace of cold and

aridity, to its eventual racial advantage. There were Triassic deserts galore, and localized areas of glaciation in the Eocene. With the Pleistocene, however, we come to a time when climatic changes made themselves felt not only by the life but by the lands themselves, due to the spreading of great sheets of ice over eight million square miles of the earth's surface, and the record of these changes is the more vivid because of the comparative recentness of the period in which they occurred. The Pleistocene represents a duration of not less than half a million years and may have exceeded a million; it came to an end when the continental ice-sheets began to melt off from Europe and North America, somewhere between 17,000 and 20,000 years ago.

The Pleistocene was not, however, a period of continuous cold, for it is now widely held that its climate changed from cold to warmer three times, and some authorities say five times. During the cold intervals there was increase in the extent and thickness of the continental ice-sheets, and during the warm interglacial stages the ice was melted back in places many hundreds of miles. The warmer times were markedly variable in duration, and at least as mild as the present; they lasted longer, and sometimes much longer, than the glacial stages.

The question at once suggests itself: Why was it that the earth, and more especially the lands of the northern hemisphere, underwent so cold a climate as that of the Pleistocene? If we can answer this question successfully, we shall also have solved the riddle of the several older glacial epochs. The solution is far from easy; it has been attempted many times, and from different viewpoints, by meteorologists, astronomers, and geologists. Some have

sought the explanation in a change of direction in the polar axis of the earth, in a marked change in the amount of heat given out by the sun, or in a great reduction of the amount of carbon dioxide in the atmosphere, due to the subtraction of it by plants and the storing of it as peat in the rocks. Another explanation ascribes the cold to fine volcanic dust shot high into the atmosphere by volcanoes and thus blanketing the earth from the sun's heat; distantly spaced blowouts would of course have no cumulative effect, but at times the earth is replete with explosive volcanoes, and this was the case during the Pleistocene. It is probable, however, that in no one of these explanations nor in any combination of them lies the key that will unlock the truth regarding the cause of glacial climates.

In earlier chapters we have seen how unsteady is the surface of the earth, resulting from time to time in the making of long chains of mountains. Usually these epochs of crustal unrest appear in a single place or in a few widely scattered ones, but every now and then there comes a time when mountains arise in relatively quick succession in one continent after another. When this happens, the lands are largest and least flooded by the oceans, continents are united by land-bridges, changing the circulation of the ocean waters, volcanoes are extraordinarily active, shooting into the air not only vast quantities of dust but carbon dioxide and steam as well. Such conditions are bound to cool the atmosphere, and yet may not be able to bring on a glacial climate like that of the Pleistocene and Permian. This was true at the close of the Mesozoic era when all of the lands were large and high, and yet no widespread glacial climate ap-

peared, only localized ones. Therefore we seem driven to say that there are times when the sun's heat is less than at others, and that this decrease in the heat received from the sun, along with the greater and higher and therefore colder lands, may be the cause of glacial climates.

But what brings on the long warm interglacial climates, such as there were in Permian and Pleistocene times? This question is the stumbling block in all of our explanations, and we can only conclude that the interaction of the various contributory causes may swing the climatic result now to warmer times and then to colder ones, until the oscillations attain equilibrium in the shape of mild normal climates. In the meantime the mountains are being shorn of their grandeur, and the air and oceanic currents become more and more normal. We must not forget, furthermore, that the sun is a variable star, and that the amount of heat which it emits varies not only from day to day but as well from year to year. The final explanation may come out of a combination of all these contributory conditions.

Although the fact of a widespread Pleistocene glaciation is now a commonplace to geologists, it was not established without much controversy. The idea, naturally enough, came out of Switzerland, where observing folk in the early part of the last century had become convinced that the erratics or boulders lying in the lowlands were left there by glaciers now high up in the mountains. Venetz, an engineer, brought this thought to the attention of Jean de Charpentier, director of mines in the Canton of Vaud, and he in turn converted to it Louis Agassiz, professor of natural science at the Academy in Neuchâtel,

thus starting the latter on a career that was finally to bring him to America as a leader in the growing scientific life of this nation. Rejecting the idea at first, Agassiz in due time became its foremost advocate, putting

A GLACIAL "ERRATIC"

The "rocking stone" in the New York Zoölogical Park, an ice-transported boulder resting on a rock pavement that has also been grooved by ice.

an end once and for all to the old theory that the scattered glacial material was the work of the Deluge. On his coming to the United States in 1846 to deliver the Lowell lectures at Boston, he found, to his delight, traces of glaciation not only at his first landing place, Halifax,

but everywhere from Boston to Lake Superior. The following year he was made professor of geology and zoölogy at Harvard, and his last resting place in Mt. Auburn is marked, fittingly, by a glacial boulder from his native land.

The immense ice-sheets that, taken collectively, lay like a mantle over the northern half of North America were of a type similar to those of Greenland and marginal Antarctica to-day: not valley glaciers descending out of mountains, but tremendously thick sheets of accumulated snow and ice that lay practically everywhere over the continent north of 40° North Latitude, obliterating valley and mountain alike. This blanket of ice extended from the northern boundaries down to a line running through the cities of Philadelphia, Louisville, and St. Louis, then swinging gradually northwestward through Topeka, Pierre, and Spokane, but leaving most of Alaska free. This is all the more remarkable when we consider that the ice-sheets, though in places more than a mile thick, were mainly of the lowlands.

Aside from Alaska, in all this upper portion of North America apparently only one section escaped the influence of the great ice-sheets—the so-called "Driftless Area," a triangle of over 10,000 square miles lying mainly in Wisconsin but overlapping slightly into the adjacent states of Minnesota, Iowa, and Illinois. This region owed its immunity, not to any superior height, but to the temporary protection of a highland to the north, and to the presence of the deep Michigan and Superior basins, which sent the flow of ice around rather than across it; had the Ice Age lasted still longer, however, it would also have been covered. Within it, the normal aspect of the un-

leveled landscape is in sharp contrast to that of the glaciated country; and to the Indians who inhabited it, the first glacial boulder beyond its western borders, near Red Rock, Minnesota, was so strange a thing as to become a subject for veneration.

North America had three main centers of snow accumulation and dispersal: the Cordilleran, from which the ice crept outward over all the western part of the continent from southern Alaska to Oregon, Idaho, and Montana; the Keewatin, in north-central Canada, from which the largest sheet of all spread westward into the high plains and southward up-grade into the central United States; and a third in Labrador, almost as great, stretching 1600 miles to the Ohio River. In general the flow was southward toward warm regions, and the maximum accumulation gradually shifted more and more to the east.

How thick these continental ice-sheets were is not known. It is generally held, however, that they must have reached depths of 4000 feet at the centers in order to have cleared the tops of the White and Green mountains, and some authorities more than double this figure. All of the water held in them had been taken from the oceans and precipitated as snow on the continents, and in consequence the sea-level in the tropics must have been lowered not less than 250 and not more than 400 feet.

As with the alpine glaciers, the fronts of these great continental ones were not constant, but advanced and retreated in response to varying climatic conditions. This is signalized both by the finding of terminal moraines at different places, and by the occurrence in the deposits of alternating cold- and warm-climate faunas and floras.

MAXIMUM SPREAD OF THE PLEISTOCENE ICE-SHEETS OVER NORTH AMERICA

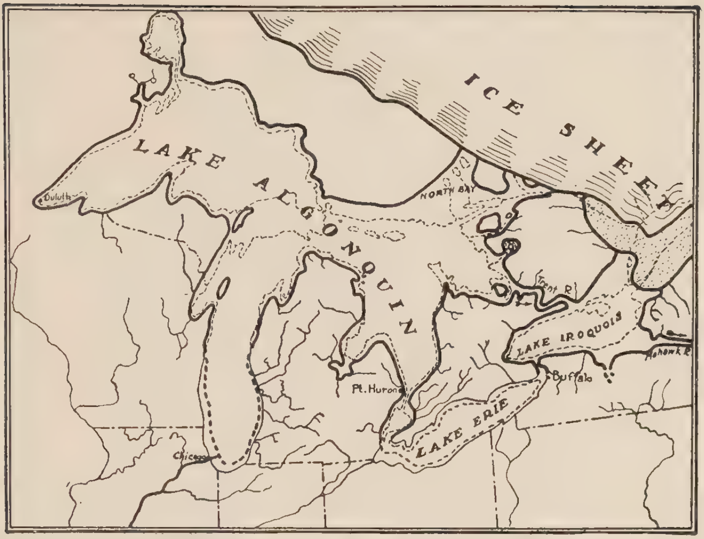
The white spot in Wisconsin is the Driftless Area, and the black ones indicate mountains covered by local glaciers. After Martin.

The great load of ice upon the lands naturally affected the topography in various ways. In the first place, the weight of the ice caused the crust to sink in the areas of the ice-sheet and to rise in those immediately outside

them. The surface of the lands was therefore more or less unsteady, warping up and down in consonance with the changes going on during the accumulation of the ice. Such down-warps frequently let the ocean in upon the land; the estuary of the St. Lawrence, for instance, was at one time about 700 feet deeper than it is now, and the Atlantic took advantage of this not only to flood Lake Ontario, but to make of Lake Champlain a salt inlet, with a shore line some 400 feet above the present one, as recorded by marine shells and bones of whales found at this height.

The drainage in front of the ice-covered areas was further modified by the drift, which filled some river valleys and made dams across the mouths of other valleys deepened by ice action, ponding the water back and leaving us such reminders as the beautiful Finger Lakes of New York. The Ohio and Missouri rivers, which, as Chamberlin says, "like two great arms embraced the borders of the greatest of the ice-sheets," were built up out of previous systems, and a host of their tributaries suffered change.

This alteration of drainage is nowhere better exemplified than in the history of the Great Lakes. The depressions in which these lakes now lie were originally in the main very ancient river valleys cut out of softer rocks after the region was elevated at the close of the Paleozoic era. At the maximum of the last glaciation the entire region was under the continental ice-sheet, but as the latter retreated, it left behind in each river basin a glacial lobe which moved forward down the depression and so continued to deepen it. Then as the ice melted, the water accumulated in the various basins as small lakes in front



THE GREAT LAKES AT ONE STAGE IN THEIR COMPLICATED HISTORY

Michigan, Superior, and Huron were united to form Lake Algonquin. with additional outlets through the Chicago and Trent rivers. Erie was larger than now, and a greater Ontario, known as Lake Iroquois, and confluent with the Champlain sea of the St. Lawrence Valley (dotted), drained out through the Mohawk. Niagara Falls was not then in existence. Modified from Taylor.

of these lobes. Finally these independent lakes coalesced into a series of larger ones which had a very complicated history of growth, shifting, combining, and shrinking, and have received many names corresponding to the various levels of the waters. At one stage in this history, Lake Duluth, the ancestral Lake Superior, drained out into the Mississippi River through the St. Croix; Lake Chicago, occupying a part of the basin of Lake Michigan, found an outlet to the same great river by way of the Illinois; while Lake Lundy, formed of Erie and Huron combined,

sent its waters down the Mohawk into the Hudson. Later lakes Michigan, Superior, and Huron united to form Lake Algonquin, the greatest of them all.

Lake Ontario, the youngest of the Great Lakes, developed out of Gilbert Gulf, which occupied the Ontario basin and united with the Champlain-Hudson estuary. After the melting of the Quebec ice-sheet, the tilting of the land brought the Thousand Islands region out of the water to form a barrier in the St. Lawrence Valley, and behind this rock-dam the waters were ponded back to form Lake Ontario, which then lay at sea-level. Subsequently, due to the rise of its outlet, its waters have risen some 250 feet to their present level.

When the latest ice-sheet was melting away but still blocked the Mohawk and St. Lawrence valleys, the Great Lakes, perhaps for a thousand years, drained southward through Fort Wayne, Indiana, to the Wabash Valley and through Chicago to the Desplaines and Illinois valleys, all of these outlets discharging into the Mississippi. The Chicago channel, being the lower, finally robbed the Fort Wayne outlet of its water, and for a long time afterward a great stream, known as Warren River, carried all the overflow of the lakes into the Mississippi. It is interesting to note that the drainage canal built by the city of Chicago to divert its sewage from Lake Michigan into the Mississippi River follows this old glacial channel. Warren River, in turn, was abandoned after the continental ice-sheet had melted away to the north and permitted the surplus water of the Great Lakes for the first time to flow southeastward through the Mohawk Valley and eventually out through the St. Lawrence estuary.

Wherever the ice-sheets have been, they have scoured

and plucked, scratched and polished the ground over which they moved, and on melting they have left in their wake, irrespective of the topography, a highly variable mantle of clay, sand, and boulders, which together are

GLACIAL "SPOOR" IN SOUTH AFRICA

Scratches and furrows made by glacial ice on Permian rocks in Africa. Photograph by Coleman.

known as drift. This usually lies with sharp differentiation upon the older mother rocks. It is extremely variable in distribution and ranges in thickness to 500 feet or more; it may fill valleys, or veneer mountains like the

Adirondacks, 5000 feet above the sea. Commonly it is an unstratified heterogeneous mass of rock laid down by the melting ice, but much of it has been well assorted and stratified by the running water from the glaciers. Coarse drift is on the whole more commonly seen in rugged regions with hard rocks, while the finer drift accompanies an undulating topography of softer strata. The drift may make the previous topography rougher or may smooth it by filling in the depressions. Most of it has been brought from nearby sources in the direction of ice flow. Probably 75 per cent of it has not been moved more than 50 miles, and yet the hard resisting boulders, like the granitic ones brought from Canada to southern Ohio, must have come hundreds of miles.

From the human standpoint, one of the most important results of the Ice Age was its effect on the soil in different regions. Where the ice encountered hard resistant rocks, the drift which it deposited contains a larger proportion of boulders and less of clay; in New England, for instance, the surface is in places so strewn with boulders as to make agriculture very difficult or almost impossible. But in the Mississippi Valley, where the rocks are softer, the drift lies over the fields in thick sheets of easily tillable soil that yields rich returns to the harvester. Moreover this soil is often greatly improved by the mixture of materials carried from one region to another, especially where a sandstone area receives contributions from one of limestone. For example, the "driftless" counties of Wisconsin yield an average of 35.5 bushels per acre as against 47.8 in the glaciated ones, the value of glaciation to the state amounting to at least $50,000,000 per year.

The development of such immense ice-fields upon the

ECONOMIC EFFECTS OF GLACIATION

Above, a glaciated area in Wisconsin; below, a New England boulder field. In the former region, the rocks traversed by the ice were horizontal and soft, thus breaking up readily into soil; while New England has an ancient rock-ribbed foundation that has been crumpled, tilted, and hardened by mountain making and consequently does not yield readily to the pulverizing action of ice. Photographs by the Wisconsin and U. S. Geological Surveys.

lands and the attendant reduction of temperature meant the blotting out of vast areas in which no life, or at least but little, could exist. The Pleistocene was, therefore, a critical time in the history of the earth, especially for the plant and animal life of the glaciated lands and the shallow-water life of the temperate and northern oceans. On the other hand, the shallow waters of the warm parts of the oceans were the asylums in which were retained the Pleistocene marine life, allowing it to continue almost unchanged into recent time.

The mammals of the Pleistocene have been discussed somewhat in the Cenozoic chapter. They made up a magnificent assemblage, inherited in part from the Pliocene, and enhanced by migrants from the Old World and more especially from South America. To mention only the more conspicuous members, the cold-climate fauna included reindeer, caribou, musk-oxen, moose, woolly mammoths, and walruses, while the warm interglacial stages had lions, saber-tooth tigers, peccaries, tapirs, camels, llamas, horses, hippopotamuses, great sloths, elephants, and sea-cows, distributed practically over the whole of the United States. The present-day fauna is probably richer in numbers, but that it is richer in kinds is doubtful, our fauna to-day north of Mexico having twenty-nine families as against thirty-seven in the still imperfectly known Pleistocene. New forms from other countries did, it is true, come to take the places of those that were dying out, but the latter, as one authority says, "included some of the noblest animals that have graced the face of the earth, the elephants, the mastodons, tapirs, many species of bison, horses, saber-tooth cats, huge tigers, and gigantic wolves."

This marked extinction during and at the close of the Pleistocene was probably due to a variety of causes, in the main connected with the presence of the great ice-sheets, each glacial and interglacial stage being presumably responsible for the disappearance of a few of the hardy types. Certain forms, however, such as the two kinds of elephants and the mastodon, survived the last glacial stage, and some other reason for their extinction must be sought.

CHAPTER XXXI

THE COMING OF MAN

PITHECANTHROPUS, JAVA APE MAN
After McGregor

MAN has long loved to associate himself with the gods of his own making, but if he is to understand himself and so make the best use of his powers for health, happiness, and spirituality, he must also study how his body is constructed, how it works, and what and where are his points of contact with the world in which he lives. As soon as he does this he begins to see that much of his organization is like that of the milk-suckling animals, the mammals, and most like that of the great apes. Even though nature has been "unduly considerate of his vanity in sparing him the full knowledge of these less attractive members of his family, who too obviously retained the mark of the beast," it is nevertheless man's first duty to know himself and his relations to the rest of the organic world, in order to understand what things he has in common with

the animals and how his strength of intellect makes him their superior.

The vision of man's evolution has come through the study of the comparative anatomy and embryology of living animals, backed by the knowledge of paleontology gained through fossils; and the rise of reason, which

THE TARSIER

One of the most primitive of the living primates. After Lydekker.

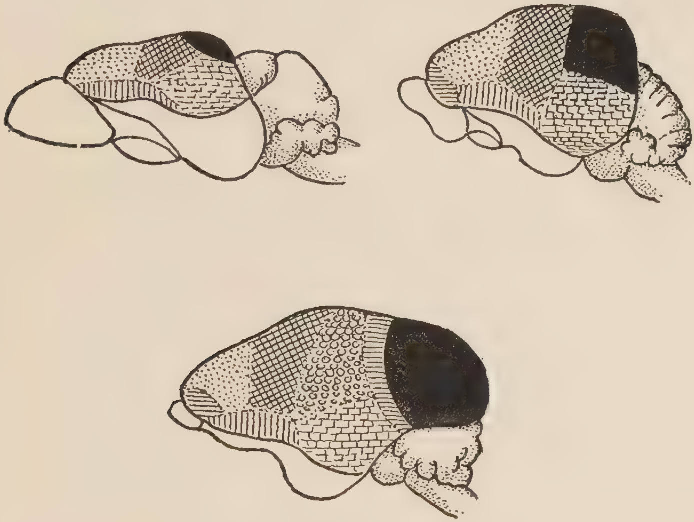
places him at the head of the animal kingdom, has been deciphered through studying the evolution of his brain. In the classification of mammals, the highest animal group, man is placed at the top of the order Primates, which includes the human family, the apes, and the monkeys. Seemingly the order had its origin in small arboreal

creatures known as tarsiids, which in turn arose from the shrews, members of the most primitive order of mammals, the Insectivora. This evolutional trend set in during the Cretaceous, and in the early Eocene the tarsiid stock of North America gave rise to the monkeys. Certain of the early shrews are thought to have taken to the trees as a habitat—a mode of living that fostered agility, developed five-fingered hands and feet for grasping the branches, and stimulated keenness of vision rather than the strong sense of smell which is usually found in ground-living mammals. It was this environment of the shrews and tarsiids, in fact, that furnished the incentive for new habits and thus brought about profound changes in, and enlargement of, the frontal area of the upper lobes of the brain, and especially of those portions that have to do with sight, touch, hearing, and memory.

Probably early in middle Eocene time, when the world climate was mild, the American monkeys spread across a northern land bridge to Europe and thence to Asia. The Alps had not yet arisen and hence very early in the Oligocene the European monkeys and the earliest diminutive apes doubtless passed over a land-bridge across the Mediterranean into Africa. This continent then became the main generating center for the higher apes and seemingly for the ape-human stock as well. The Dark Continent is now beginning to yield up its primate fossils, and we are on the verge of great discoveries in the way of connecting links.

Structurally, man and the other anthropoids are very similar, the skeletal differences being caused by man's more erect posture and his changed mode of living. The erect posture is of ancient origin, for it appears to have

been present in the oldest known man, *Pithecanthropus*. It is not, however, so much in posture itself that man differs from the other large anthropoids as in manner of progression. The larger apes spend the major portion of their time in the trees, and their strong fore limbs are

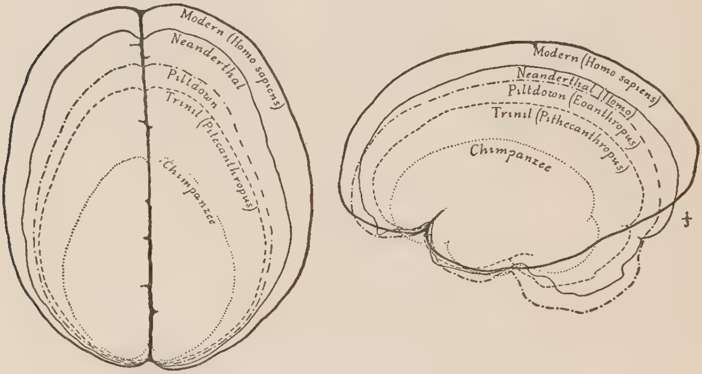


THE DEVELOPMENT OF VISION

Contrast the amount of brain area devoted to vision (marked black) in the jumping shrew (left above), which lives on the ground, and in its cousin, the tree-living shrew (right above). Below is the brain of the arboreal tarsier, one of the primate stock to which man belongs. After Elliot Smith.

especially adapted for swinging from branch to branch. Man, on the other hand, is fitted to live on the ground, "an adaptation which allowed him to escape from the limits of forests and occupy the whole world." This change of habitat resulted in a relative shortening of the

fore limbs and a greater development of the legs, which now bore all the weight of the body. The human type of leg and foot, then, was developed long before the human brain came to be as we see it now. The large and more intricate brain of man is his latest acquisition; his foot, leg, and gait are older, his size of body older still, and his erect posture quite an ancient character.



BRAIN OF CHIMPANZEE AND MAN

Note the progressive increase in size, from ape through ancient to modern man. After Osborn.

On the basis of the degree of perfection shown by his stone implements, man's early history has been divided into an Old Stone Age and a New Stone Age. The time of the Old Stone Age is that of the late Pliocene and most of the Pleistocene, and everywhere the men of this time were hunters and makers of the crudest of stone implements. In many places have been found large and small stones, chiefly of flint, which have rudely chipped edges and resemble weapons made by primitive man.

These crudest of implements, known as eoliths, are older than the oldest known human bones, and there is also direct evidence of man-made fires occurring in the late Pliocene strata of southeastern England.

The oldest well-made human implements are known as paleoliths, and the older ones among these are still very crude in workmanship, being merely nodules of flint,

IMPLEMENTS OF ANCIENT MAN

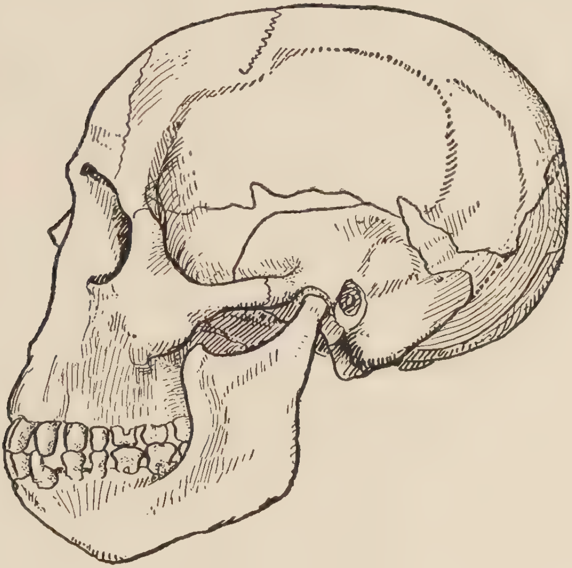
These were made by chipping flint, a rock that breaks with a sharp edge, and were used for cutting or scraping. The one on the left (eolith) is the most primitive. From MacCurdy, *Human Origins*.

reduced to the required shape and size by means of oblique blows delivered to the right and left. For the greater part they are rude scrapers and knives. None of them appear to be weapons of the chase, but their makers were undoubtedly learning how to hunt animals for food and how to defend themselves by their greater skill in the invention and use of improved killing devices.

The oldest known bones of the human family are those of *Pithecanthropus,* the ape-man, thought to date from the earliest Pleistocene. They were discovered in 1891 at Trinil, Java, together with remains of many kinds of animals that are now extinct on the island. The human remains consist of the upper part of the skull, three molar teeth, and the entire left lower leg bone (femur). From the last, the height of the ape-man is estimated to have been 5 feet 6 inches. The skull has a very low crown with prominent eyebrow ridges, the forehead is more receding than that of the chimpanzee, and the volume of the brain is estimated at 988 c.c. This ape-man is the most primitive known representative of the human family, but in his mental development he had risen far higher than halfway between the apes and modern man. The brain case shows clearly that *Pithecanthropus* had already developed rudimentary speech. He was probably not in the direct line to the higher types of man, but represents a specialized and unprogressive branch which became extinct in the Pleistocene.

The oldest known remains of the human family in Europe, the "dawn man," *Eoanthropus,* were found in 1912 in the plateau gravels at Piltdown, Sussex, England. Much of the skull and jaw is present, permitting of a complete restoration of the head. The lower part of the face is decidedly prognathous or "snouty," the forehead, although narrow, is not receding but as steep as in modern man, the brow ridges are feeble, and the brain case is very thick, with a content of nearly 1,070 c.c., thus comparing favorably with that of the average modern man, which has a content of between 1,400 and 1,500 c.c. The chinless lower jaw, with its large canines, is dis-

tinctly simian, but the anatomical peculiarities of the jaw and teeth prove them to pertain to a primitive human being. In other words, the brain had attained the



SKULL OF PILTDOWN MAN

Reconstruction of the much-discussed skull of the "dawn man" of Piltdown, which combines a human cranium with a lower jaw and teeth that are distinctly chimpanzee-like. After Smith and Hunter, from MacCurdy.

human stage at a time when the jaws and face, and no doubt the body also, still retained many of the simian characteristics.

With *Eoanthropus* were associated in the plateau gravels very ancient types of paleoliths, and the age of these beds is regarded as of the second interglacial warm epi-

sode, when the hippopotamus lived in England; this was about early middle Pleistocene time.

In 1856 most interesting human remains were found in a cave in the little valley known as the Neandertal, lying between Düsseldorf and Elberfeld, Germany. Since then, remains of many men, women, and children of this so-called Neandertal race have been found in caves and rock shelters in Belgium, France, Gibraltar, Croatia, and recently near Jerusalem. Their implements, however, are found scattered throughout western Europe and eastward into Poland, the Crimea, and Asia Minor. In France these people are known as the Mousterians, and they were probably the first humans who dwelt in caves. It is believed that they wandered from Africa into Europe by way of the Iberian Peninsula. They lived during the last glacial episode, when the climate was cool and finally cold, a time estimated to have been anywhere from 60,000 to 150,000 years ago. It was the time of the bison, horse, reindeer, cave bear, cave hyena, woolly rhinoceros, and woolly mammoth, on some of which the Neandertal race subsisted. The race lived for a long time geologically, persisting into the New Stone Age.

The Neandertal people clearly belong to the genus *Homo,* which embraces modern man. Averaging about 5 feet 4 inches tall, they had large heads with a cranial capacity not far from 1,400 c.c. On the other hand, Neandertal man was uncouth and repellent in appearance; to quote Elliot Smith, one of the greatest British authorities:

> His short, thick-set, and coarsely built body was carried in a half-stooping slouch upon short, powerful, and half-flexed

legs of peculiarly ungraceful form. His thick neck sloped forward from the broad shoulders to support the massive flattened head, which protruded forward, so as to form an unbroken curve of neck and back, in place of the alternation of curves which is one of the graces of the truly erect *Homo sapiens*. The heavy overhanging eyebrow-ridges and retreating forehead, the great coarse face with its large eye-sockets, broad nose, and receding chin, combined to complete the picture of unattractiveness, which it is more probable than not was still further emphasized by a shaggy covering of hair over most of the body. The arms were relatively short, and the exceptionally large hands lacked the delicacy and the nicely balanced cooperation of thumb and fingers which is regarded as one of the most distinctive of human characteristics.

At least two of the skeletons were found in their original burial places, and here were also laid away implements, plants, and food, indicating a ceremonial interment and offerings to assist the departed in the spirit world.

In 1921 two human skeletons were discovered in a cave at the Broken Hill mine in northern Rhodesia, Africa. They were found associated with a great abundance of mammal skeletons, but all these are of living species that had been dragged into the cave by hyenas. Therefore *Homo rhodesiensis* does not certainly go back into geologic time, and yet his development reveals the most primitive type of face that is known among members of the genus *Homo,* with eyebrow ridges that exceed in size even those of Neandertal man.

Coming now to the New Stone Age, we arrive at the dawn of human civilization. This development emerges in the latest Pleistocene and continues into historic time.

The stone culture, now of the so-called Neolithic type, is improving rapidly, since the chipping of the flints is of the highest excellence, and, in addition, many of the weapons and tools are rubbed into shape and often polished.

The people of the New Stone Age began to make pottery and introduced the herding of cattle and communal life. Later on permanent habitations in stone huts and skin wigwams, along with agriculture, became more general. Finally the metals copper, gold, and iron were discovered and methods learned for their use. Definite migrations and warfare began also with these people, and manufacturing and trading as well.

The oldest known Neolithic peoples were the Aurignacian race of *Homo sapiens.* At first they were still hunters, but had far greater skill in the making of stone and bone implements than did their predecessors, the Neandertals, whom they dispossessed. They appeared in western Europe at about the close of the Glacial Period, or around 20,000 years ago. Coming from the east, they spread westward from Asia Minor, and their remains are found throughout the greater part of western and central Europe and most of the Mediterranean countries.

The Aurignacian implements were still of the late Paleolithic type, but the workmanship of the flints was better and constantly improved with time, and the race had many more kinds of tools to serve more purposes—the making of spears, bows and arrows, and fur garments. Themselves they ornamented with marine snail shells derived from the Mediterranean and the Atlantic, with fossil shells from far inland places, with teeth of mammals, and even with those of other human beings,

and later with beads, bracelets, and other objects manufactured out of shell and ivory.

With the Aurignacians came the actual development of the fine arts, first in bodily ornament and clothing, and then in drawing, painting, and sculpture. Examples of their art are preserved in the caves of France and Spain, where the walls and ceilings are often highly decorated, and their achievements along these lines excite the wonder and admiration of all who view them.

The dawn of human civilization began roughly about 18,000 B.C. in Asia Minor, Arabia, and Persia, the people of the Persian city of Susa apparently going back to 16,000 B.C. and the mid-sea people of Crete in the eastern Mediterranean to about 12,000 B.C.

All living human beings, whether white or black, yellow or red, are but races and varieties of a single species, *Homo sapiens*. The most primitive race is the native Australian, while the negroes are somewhat higher and of later origin. Both races are black and this color is believed to be primitive and common to all the older species of the human family. Loss of pigment in the skin began to be marked in the Mongolians, and was greatest in the Mediterranean-Nordic peoples.

So far the fossil evidence which we have been discussing has been entirely from the Old World. When we come to our own continent, however, there is no such wealth of record. Many times in the past the remains of fossil man have been found in the United States in such geological associations as to lead their discoverers to assert the presence of man in strata made in Pleistocene time, but the great antiquity of this evidence has in almost every case been denied by anthropologists. Nevertheless,

we are coming to see more certainly that man has been in North America at least 10,000 to 20,000 years. The Indians are of Asiatic origin and probably came to this continent by way of the Siberia-Alaska land-bridge, now covered by a very shallow sea. In recent years, evidence is accumulating to show that Polynesian peoples spread across the Pacific and got a foothold in South America, whence they went northward into Mexico; these are the Incas and the Aztecs. Accordingly the older records of man are to be looked for along the Pacific, in Mexico, and in the Southern States, and it is indeed in California, Arizona, Mexico, and Florida that the oldest human evidence is at hand.

At San Angel, a southern suburb of the city of Mexico, human skeletons have been found, along with implements, beneath 15 to 30 feet of lava. To the northwest of this same city, identical implements are found beneath 10 to 12 feet of sediments, and this is thought to indicate an antiquity for the remains of not less than 2000 years, and possibly five times as much.

Human remains, together with bits of pottery and charcoal, have been recovered at Vero on the Atlantic coast of Florida, and since they are associated with the bones of extinct mammals, it is held that they may be of an antiquity of as much as 50,000 years. There is much other similar evidence for human antiquity in the United States, and some of it shows that these ancient peoples were acquainted with elephant-like animals. The Aztecs, for example, pictured such on the temple of Copan in Yucatan, the prehistoric mound builders built elephant-shaped mounds in Ohio and Wisconsin, and fashioned elephant pipes in clay—facts which appear to place beyond

HOMES OF PREHISTORIC CAVE DWELLERS IN NEW MEXICO

Cliffs such as these, of soft stone, furnished safe dwelling places for ancient man, both in this country and in Europe. After Prudden.

doubt the probability that the mound-building Indians, the mastodon, and a species of elephant lived together in North America anywhere from about 5000 to 15,000 years ago.

In summation, we have seen that at first it was vision rather than smell that was the guiding sense of the primate line. Then came the freeing of the hands as locomotor organs, and their development into those for prehension and handling; and the further cultivation of this manual skill, along with still greater perfection in vision and hearing, growing inquisitiveness, and finally the rise of speech, led to man's mental ascendancy through the development of new brain centers, which in turn established his supremacy in reasoning out the causation of

things. Continually renewed adaptations led to the enlargement and the greater complexity of structure of the upper lobes of the brain and more especially their frontal portions, a development that gave rise to the high front of the skull, "the distinctively human forehead."

In the late Pliocene, man in England already knew how to kindle fire, and the Neandertal race buried their dead with their implements, paints, and ornaments, showing the dawn of some religious feeling. With the appearance of the Aurignacians, modern man was at hand, and his mentality now dominates the organic world, and bids the forces of Nature do his work.

Human mentality has risen far above that of any other part of the organic world, and to it all creation will soon be more or less subservient. Through his inventions, man will eventually control his environment and largely nullify the laws of natural selection and survival of the fittest to which all other organisms are subject. His further progress, however, is dependent upon himself, dependent upon whether he will learn to control himself for the benefit of human society, as the clashings of men and civilizations are still due to his inborn predatory instinct.

Man has long been asking and always will be asking the question of questions: What is the philosophical meaning of our emotions, our superstitions, our aspirations, hope, and love? These are the fundamentals of the religion that is in all of us, the "feeling after God," the "Great Unknowable" of Spencer. Looking down the vista of ascending man, we see that his yearnings as expressed in creeds are in constant evolution, rising from a belief in endless numbers of gods to that in one God,

and now we are beginning to see that man's first duty is service to humanity. But the question of the great Ultimate Cause, which set the stars in infinite space and established the immutable laws that have brought the earth into being and made it a habitation fit for man, is one to which science has as yet found no answer.

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(*Items marked* (*) *indicate illustrations*)